ARCTIC

OLUME 10, NUMBER 1 · 1957

URNAL OF THE ARCTIC INSTITUTE OF NORTH AMERICA

THE ARCTIC INSTITUTE OF NORTH AMERICA

The Arctic Institute of North America was founded to further the scientific study and exploration of the Arctic. The Institute provides information on the Arctic through its four offices, awards research grants, and publishes scientific papers and other contributions in its journal *Arctic*. Those interested in this work are invited to become Members. Members receive all numbers of the journal. The Library and Map Collection at the Montreal Office are principally for their use, and they are welcome there and at the other Institute Offices. Membership dues are $5.00 annually. Registered students under the age of 25 years may pay a reduced fee of $3.00. All remittances should be sent to the Ottawa Office.

Offices of the Institute

3485 University Street, Montreal 2, Que., Canada
388 Elgin Street, Ottawa 4, Ont., Canada
1530 P Street N.W., Washington 5, D.C., U.S.A.
2 East 63rd St., New York 21, N.Y., U.S.A.

ARCTIC

Journal of the Arctic Institute of North America

Vol. 10, No. 1 Published in Ottawa, Ontario **1957**

CONTENTS

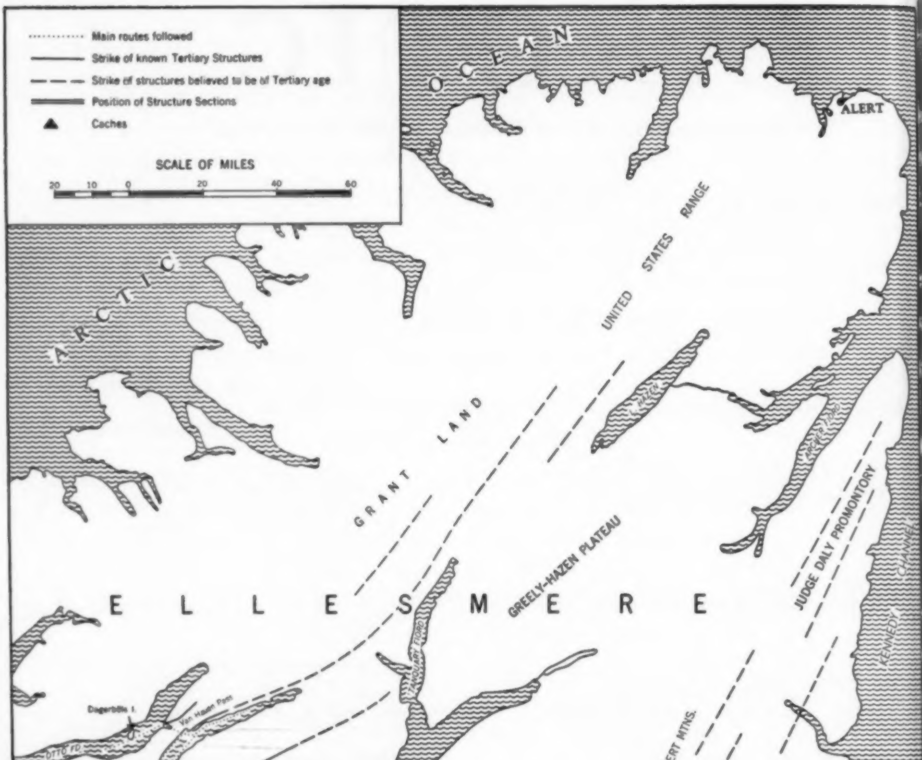


Fig. 1. Sketch map of parts of Ellesmere and Axel Heiberg islands.

GEOLOGICAL INVESTIGATIONS IN ELLESMERE AND AXEL HEIBERG ISLANDS, 1956*

R. Thorsteinsson and E. T. Tozer†

During the past six years members of the Geological Survey of Canada have been investigating the geology of the Queen Elizabeth Islands. Parties have worked from the weather stations at Resolute (Thorsteinsson and Fortier, 1954; Thorsteinsson, 1955), Isachsen (Heywood, 1954), Alert (Blackadar, 1954) and Mould Bay (Tozer, 1956). R. L. Christie (1955) represented the Survey on the 1954 Northern Ellesmere Expedition of the Defence Research Board (Hattersley-Smith *et al.*, 1955). In 1955, with the aid of helicopters, the members of "Operation Franklin", a Geological Survey project directed by Y. O. Fortier, studied the geology of many parts of the country too far from the weather stations to be readily accessible. At the beginning of 1956, the surroundings of only one weather station in the islands, Eureka on the west coast of Ellesmere Island, had not been systematically explored by the Geological Survey. From the studies of Per Schei (*in* Sverdrup, 1904) and J. C. Troelsen (1950, 1952) it was known to be an area of considerable interest, and this conclusion was confirmed by an examination of air photographs. Consequently, the writers undertook an exploration of this area for the Geological Survey between April and September 1956.

The use of the Eureka Weather Station as a base was made possible through courtesy of the Meteorological Division, Air Services, Department of Transport. We wish to express our gratitude to the Director of the Division, Dr. Andrew Thompson, and also to the Canadian and United States personnel at Eureka for their hospitality and assistance. Transportation to and from Eureka was provided by the R.C.A.F., to whom we are indebted. We are also grateful to the Commanding Officer of the Thule Air Base, Colonel Frank W. Ellis, U.S.A.F., and Major Claude P. Spence, U.S.A.F., for their generous assistance.

In the course of our field work we travelled by dog team, on foot, and by powered canoe. A full technical report of the work will be published by the Geological Survey of Canada. The present account describes our various journeys and summarizes briefly the geological results of our field work, which have led to a modification of the earlier interpretation of the age and extent of the mountain folding in west central Ellesmere Island. These problems have engaged the interest of many geologists since Per Schei, of

*Published by permission of the Deputy Minister, Department of Mines and Technical Surveys, Ottawa.

†Geologists, Geological Survey of Canada.

the Second Norwegian Polar Expedition in the "Fram", first described folded Mesozoic rocks in Eureka Sound. They are not entirely unfamiliar to readers of this journal, in which Troelsen (1952) described the results of his recent investigations in Ellesmere Island.

Field work

The main routes followed in the course of our field work are shown in Fig. 1. Thorsteinsson arrived at Eureka on April 23 with our first load of equipment and supplies; Tozer followed on April 26 with two Eskimo dog drivers, Amagualik and Jebbedi, engaged at Resolute Bay, 20 dogs, and the rest of the equipment.

We expected that there would be three phases to our field work. For the first we planned to use dog teams as far into the summer as possible; then to travel on foot, extending our range by using caches deposited in the sledging season; and finally, after break-up of the sea ice, to operate from a canoe.

Our sledging started with two trips to the "Sawtooth Range"* to lay out food caches for summer travel on Fosheim Peninsula.

On April 28, Tozer, with Amagualik, left for the lake situated in the prominent wind gap of the "Sawtooth Range", 48 miles southeast of Eureka. From the head of Slidre Fiord the route lay overland. Travelling conditions were poor and it took three days to get to the upper reaches of a watercourse some eight miles from the lake. From a camp left at this stream the party ascended a narrow ravine with a lightly loaded sledge and so reached the plateau adjacent to the "Sawtooth Range" and the lake. According to the only published map showing this lake (the U.S.A.F. chart) it drains west into Eureka Sound. Actually the outlet runs east, then south and eventually into Vesle Fiord. Approaching from Eureka Sound it was therefore necessary to cross the watershed of the "Sawtooth Range" in order to reach the lake, which was covered with rough old ice, clearly more than one year old. Cache 1 was left at the east end of it and here a fine view of the head of Wolf Valley and of the ice-capped mountains beyond was enjoyed.

In returning to Eureka the large river that flows into Eureka Sound opposite Depot Point was followed and from its mouth the party travelled up the sound to Slidre Fiord. Cache 2 was left in the river valley about nine miles inland. Bad weather hampered our field work in July and neither of these caches was actually used. The sea ice on the east side of Eureka Sound between the mouth of the river and Blue Man Cape had been subjected to much pressure and was very rough. Fortunately, it was possible to avoid this bad stretch. Excellent travelling was found on the low shore. Here iced runners that had been of little use farther inland, owing to the many rocks, were a great help. At Blue Man Cape the party took to the ice of the sound. The 50 miles from the river's mouth to Eureka were covered in about 11 hours on May 3.

*Names that appear in quotation marks have not yet been adopted by the Canadian Board on Geographical Names.

Meanwhile, Thorsteinsson and Jebbedi had left Eureka on April 29 on the other cache-laying journey. From the head of Slidre Fiord they followed Slidre River for about 12 miles. The river was then abandoned for a direct easterly route over the dissected plain that lies west of the "Sawtooth Range". Foggy weather lasting from the evening of April 29 until May 1 made it impossible to follow it as planned. When the fog lifted it was found that the party had entered the foothills of the "Sawtooth Range" some 8 miles south of the valley where the main cache was to be laid. It was therefore necessary to sledge north along the mountain front to the stream that runs through a prominent wind gap in the range, 8 miles southwest of Cape With, where cache 3 was left. From this valley an attempt was made to cross the mountains to Wolf Valley, but the sledge was becoming so badly damaged by the rocks projecting through the snow that this plan had to be abandoned. Wolf Valley was discovered in 1901 by Fosheim and Raanes, of the "Fram" Expedition, in the course of their exploration of Canyon Fiord. From Canyon Fiord they travelled up the valley hoping that it might lead to a short cut back to Eureka Sound, and so speed their return journey to the ship. However, they found their way blocked by the mountains now known as the "Sawtooth Range". A sledge route may exist up a branch of Wolf Valley and then along the lake visited by Tozer.

After depositing cache 3, Thorsteinsson travelled down the river that reaches Canyon Fiord west of Cape With. The fiord ice was smooth and covered with hard snow and these conditions provided a welcome change from the poor sledging encountered on the land. The travelling in Greely Fiord was made disagreeable by high sastrugi, much hummocked ice, and a persistent northwest wind, but improved ice conditions and shelter from the wind were found in Eureka Sound. On May 4 the party was back at the weather station.

Both parties found sledging on the plains of Fosheim Peninsula very poor owing to the ubiquitous boulders of morainal origin. These boulders, and the thin snow cover, made it difficult to find a route for the sledges. We had the same experience as Troelsen, although our difficulties were not comparable with his, for we had dogs to draw our sledges whereas he was pulling his pulka himself (Troelsen, 1952). Thorsteinsson used a large komatik shod with fabric-bound bakelite, made for the Geological Survey in 1954 by the engineering staff of the National Museum of Canada, under the direction of Mr. J. W. Van Alstine. In the past the bakelite shoeing had proved satisfactory on snow and particularly so on bare sea ice, when sledging late in the season. However, it was quite unsuited to travelling over the bouldery terrain of Fosheim Peninsula and on this one journey of some 120 miles, less than half of which was over land, the shoeing was damaged beyond repair. At Eureka the komatik was shod with steel and gave excellent service afterwards.

After completion of cache-laying we decided to travel together across Greely Fiord and start geological work in Borup Fiord. On May 8 we left Eureka on a good surface, but on the following day, as we neared the north side of Greely Fiord west of Atwood Point, we encountered soft snow. On

May 10, near the mouth of Borup Fiord, the snow became deeper. Borup Fiord had been visited only once before—by A. Elmer Ekblaw of McMillan's Crocker Land Expedition in 1915. We had read his account (*in* McMillan, 1918, Appendix I) and were not entirely unprepared for these conditions. At this stage of the journey we therefore took to the skis that we had brought in anticipation of finding soft snow. During most of the time in the Borup Fiord country we skied, usually ahead of the dogs in order to prepare a trail; without skis we almost invariably sank in the soft undrifted snow to above our knees and often to our waist.

Our object in visiting Borup Fiord was to study the geology of the mountain range that curves southwest from the head of Borup Fiord to meet the coast of Greely Fiord at Blue (Blaa) Mountain. Accordingly we travelled up the wide valley that enters the west side of Borup Fiord near the mouth of Oobloyah Bay. Here, as in the fiord, we had deep soft snow right up to our final camp a mile or so from the glacier at the head of the valley, which we reached on May 12. We spent two days studying the geology of this area, and despite the handicap of the soft snow considerable information was gathered on the late Palaeozoic and Triassic rocks that form the mountain range. Nevertheless, it must be admitted that conditions were far from satisfactory for our study (Fig. 2).

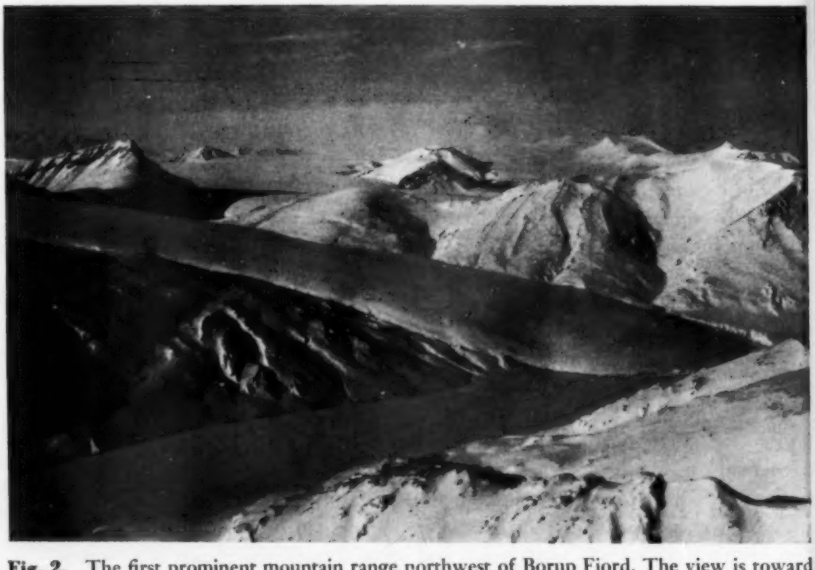


Fig. 2. The first prominent mountain range northwest of Borup Fiord. The view is toward the northeast from a point about 12 miles northwest of the mouth of Oobloyah Bay. The mountains are composed of folded Permian and Triassic rocks. The structure shown is essentially anticlinal with northwest dips to the left and southeast dips to the right. May 13, 1956.

With a trail to follow we made better time on the return journey and on May 15 camped just east of Atwood Point. We had spent six days in the Borup Fiord region and the weather during this period had been exceptionally calm and sunny. Practically all the time while we were there it was so still that one did not need to shield a lighted match. The surface of the snow, both on land and the sea ice was perfectly smooth and quite devoid of wind drift features. Borup Fiord must have an unusually well sheltered situation.

Fig. 3. White gypsum measures with dark bands of limestone overlain by black impure limestones and shales of Permian age. North side of Hare Fiord, 1 mile northwest of "Van Hauen Pass". June 2, 1956.

From Borup Fiord we travelled to the impressive cliff of Blue Mountain, where Per Schei collected Triassic fossils in 1902. Two days were spent studying the geology of this area, where we immediately realized that we had left the shelter of Borup Fiord. The land had much less snow and the ice was covered with hard drifts. From Blue Mountain we returned to Eureka, arriving there on May 20.

During the next two weeks, Thorsteinsson returned to northern Ellesmere Island and Tozer visited eastern Axel Heiberg Island. Thorsteinsson, again with Jebbedi, left the weather station on May 24, bound for Hare and Otto fiords. Examination of air photographs had revealed that the region was characterized by moderately high relief and good rock exposures. Moreover, interpretation of the air photographs of Hare and Otto fiords in the light of

experience gained on the Borup Fiord journey seemed to promise good exposures of Upper Palaeozoic rocks. On the Hare Fiord photographs a prominent white formation appears, which resembles an interesting, although relatively poorly exposed unit of gypsum measures that we had found northwest of Borup Fiord. In view of the possible (and later established) relationship of these deposits to those forming piercement structures in Axel Heiberg Island and the Ringnes Islands, a more exact dating than was obtained at Borup Fiord seemed desirable (Fig. 3).

Fig. 4. Cliff of upper Triassic strata on south side of Hare Fiord, a short distance northeast of the prominent bend in the fiord. The strata, apparently flat-lying, in fact are dipping gently toward the observer. June 2, 1956.

The east coast of Schei Peninsula was followed to Butter Porridge Point, which was reached on May 26. Much of the peninsula was bare of snow except for drifts remaining in the deeper valleys and stream beds. At the point Eskimo tent rings were seen that presumably represent those found by Sverdrup and Schei (Sverdrup, 1904, Vol. II, p. 205). From the northwestern extremity of Schei Peninsula, Nansen Sound was crossed to reach the peninsula lying between Hare and Otto fiords, the coast of which was followed to the entrance of Hare Fiord. This coast is bounded by nearly vertical cliffs composed mainly of dark grey and black rocks, that rise to a height of about 1,500 feet. On May 28 these cliffs were entirely free of snow; working on them proved pleasantly warm, and meltwater was seen for the first time in the season. These cliffs probably represent the feature named "Black Mountain"

by Sverdrup. Travelling conditions from Slidre Fiord to Hare Fiord were fair. Nansen Sound, and Greely Fiord, in contrast to the sheltered fiords to the north, are evidently virtual wind funnels and here the ice was covered with sastrugi and other drift features. A patch of badly hummocked ice about two miles wide and a pressure ridge marked the entrance to Hare Fiord, but inside the fiord the snow and ice conditions were in remarkable contrast to those of the other regions visited. Drift features were rare, the ice was perfectly smooth and the snow seldom deeper than three inches. The surface was almost too slippery for comfortable walking, but there was sufficient snow to give the dogs a foothold. The land surrounding this long fiord was also mostly free of snow (Fig. 4).

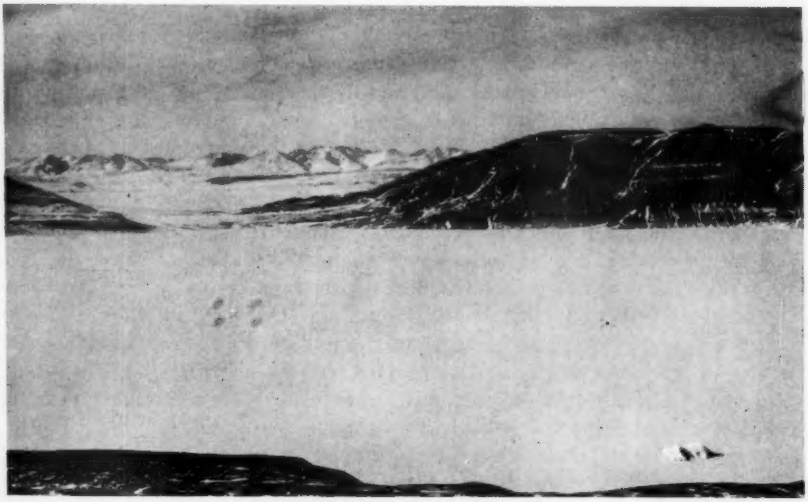


Fig. 5. Northwesterly view across Hare Fiord to "Van Hauen Pass" and Otto Fiord. The pass is left of centre and the snow covered mountains in the background are northwest of Otto Fiord. The light coloured beds forming the lower prominent cliffs to the right (northeast) of the pass are composed of the gypsum formation within the Pennsylvanian-Permian sequence. Above the gypsum are black impure limestones and shales of Permian age. May 30, 1956.

Hare Fiord was followed to within about 16 miles of its head; the party then turned back and on June 2 camped on the summit of the pass (approximately 150 feet above sea level) between Hare and Otto fiords. This pass was discovered in 1940 by James Van Hauen, leader of the Danish Thule-Ellesmere Land Expedition (Vibe, 1948, p. 180). There was very little snow in the pass and only by following a tortuous route was it possible to sledge across it (Fig. 5).

On June 3 the party reached Otto Fiord and proceeded towards Degerböls Island, named by the Van Hauen Expedition. Again a profound change in snow conditions was experienced. Both land and ice were covered with a heavy mantle of snow and outcrops were visible only on the steepest cliff faces. In the first five miles from the pass the depth of snow increased from about five inches to two feet. Twelve miles west of Degerböls Island the snow was up to three feet deep. Here it was decided to return to Eureka by way of Hare Fiord rather than continue down Otto Fiord in deep snow that made geological work well nigh impossible. On June 7 the party was back at the weather station having travelled about 250 miles since May 14.

Between May 24 and June 7 Tozer, accompanied by Amagualik, studied the east coast of Axel Heiberg Island between Skraeling Point and Mökka Fiord. During this period five days were spent at Buchanan Lake* southwest of the head of Mökka Fiord.

Smooth ice provided excellent travelling along most of the coast of Axel Heiberg Island, but an unusually bad surface was encountered in Mökka Fiord where the ice was much hummocked and in many places covered with up to six inches of wind-blown sand, grit and mud. Mökka is Norwegian for muck and the fiord is appropriately named. The narrow neck of land separating Mökka Fiord from the lake was practically free of snow except for an occasional small snowbank immediately adjacent to the river. Old Eskimo tent rings and some structures that Amagualik called fireplaces were found here. The ice on the lake was smooth, almost completely devoid of snow and, like the fiord to the east, locally covered with wind-blown detritus. The surrounding mountain sides were also virtually snow free. In July 1953 a Canso aircraft landed George Jacobsen and his party on this lake which normally seems to be free of ice in the summer. As suggested by A. C. Fryer of the R.C.M.P. (Arctic Circular, 1954, p. 35) dirt blown on the surface of the lake apparently accelerates the melting.

On June 10, travelling together, we left Eureka on our last sledge journey. We had originally planned to go straight to Canyon Fiord, but in view of the interesting geological problems to the north we finally decided to do more work near Nansen Sound first. We travelled straight up to the peninsula between Hare and Otto fiords. It took two days to reach our destination and June 12-18 were spent examining the coast between the two fiords. On June 16 high southeast winds melted practically all the remaining snow on the ice, adjacent to the cliffs. On June 19 we crossed Hare Fiord and made our last camp in northern Ellesmere Island on the east side of the fiord. Nearby were seven Eskimo tent rings and numerous musk ox bones encrusted with orange lichen. On June 22 we concluded our field work in northern Ellesmere and returned to Fosheim Peninsula. In Greely Fiord nearly all the snow had melted on the ice and the surface was covered with pools of water up to 3 feet deep. On arrival at Iceberg Point we found a substantial shore lead and this feature was to hinder our work from then on. From Iceberg

*Buchanan Lake is now the official name for this body of water. In the past it has been called "Maersk Lake" (Vibe 1948, p. 180) and "Diana Lake" (Porsild, 1955, p. 35).

Point we travelled to East Cape in Canyon Fiord where we spent two exceptionally warm and sunny days studying the geology. It was now June 29, the rough ice was very hard on the dog's feet, and we were not adequately supplied with dog boots. Canyon Fiord was traversed by wide cracks and the shore lead was making it increasingly difficult to get from the ice to the land. The Eskimo were loath to travel any farther up the fiord and we felt that their misgivings were justified. Regretfully we returned to Eureka. This occupied four days of fine weather and early in the morning of July 3 we were back at the weather station. The shore lead made it practically impossible to study the coast on the way. Between the west shore of Canyon Fiord, a few miles north of Cape With, and Iceberg Point, only one ice bridge (near Mount Lockwood) remained.

The greater part of July and the first week of August were devoted to studying the geology of the Eureka region. Although most of this work was done on foot, by July 9 the shore lead on the south side of Slidre Fiord was wide enough to travel by canoe to the head of the fiord. Between July 9 and 19 we walked to the "Sawtooth Range" over the low, well vegetated plain that rises gently from Slidre Fiord to the mountains. Bad weather delayed the geological programme in the mountains and we abandoned our planned circular traverse, for which the two southern caches had been deposited in the spring (Fig. 6).

Fig. 6. "Sawtooth Range", 12 miles south of Cape With. The mountains are composed of Permian rocks dipping toward the observer, with the overlying Triassic and younger Mesozoic strata forming a monoclinal terrain in the foreground. The white Mesozoic sandstones to the left are overlain by a thick deposit of bouldery glacial till. Such deposits are widely distributed on northern Fosheim Peninsula. The relatively rich vegetation seen in the foreground characterizes the stream valleys west of the "Sawtooth Range". July 15, 1956.

On our return from the "Sawtooth Range" on July 19 much of Slidre Fiord was free of ice and we started planning the final phase of the field work which involved taking the canoe into Eureka Sound and travelling to the head of either Bay Fiord or Canyon Fiord.

The head of each fiord lies some 135 miles by water from the weather station and both are regions of considerable geological interest. It was our plan to travel as quickly as possible to the head of one of these fiords and to undertake the greater part of the geological work on the return journey. We had decided to let the ice conditions govern our choice.

On July 30 the ice in Eureka Sound between Blue Man Cape and the south end of Schei Peninsula was broken into large pans that were moving southward. By August 7, when travel was possible down Eureka Sound, both Greely and Canyon Fiords were seen from the top of "Black Top Ridge" to be filled with fast, although well fissured ice. On August 8 we therefore left Eureka for Bay Fiord in the 22-foot freighter canoe used by Thorsteinsson for four years at Cornwallis Island. The load amounted to about 1½ tons, which included 85 gallons of gasoline, a spare motor, and also light travelling gear for use in the possible event of ice conditions interfering with our return. On the first day we made a good run of about 30 miles through comparatively ice-free water before being stopped by heavy pack ice east of Blue Man Cape. From here pack ice appeared to fill Eureka Sound as far south as we could see. We were unable to travel for four days, during which time the ice moved more or less continuously up the sound, at a rate of about two or three miles an hour. The movement ceased or slackened only for short periods at the turn of the tide. Most of the pack was composed of light floes but heavy, hummocked floes and icebergs occasionally joined the northerly parade. After the second day of delay the ice seemed to loosen and a persistent lane of water appeared along the Axel Heiberg shore, on the opposite side of the sound. On August 11 we attempted to cross the sound to Depot Point, but when we left the shelter of a large ice pan a moderate sea in the middle of the sound forced us to return. On the following day the ice movement suddenly reversed and at the same time the pack became sufficiently loose for us to continue southward. For the first three hours our progress was slow as we threaded our way around pans and through brash ice, but about 30 miles north of Vesle Fiord we entered open water which extended right down the sound to the mouth of Bay Fiord. August 13 was calm and sunny and we continued up Bay Fiord to Irene Bay. Late that evening we made camp about a mile from Thumb Mountain, the prominent land mark at the west end of the Sverdrup Pass, which leads to Flagler Fiord. On this occasion Bay Fiord was virtually without a trace of ice and we could see that Strathcona Fiord, its southeastern arm, was in a similar condition (Fig. 7).

For eight days we studied the geology of the innermost parts of Bay Fiord and examined the rugged and picturesque mountains west of Irene Bay. It was these mountains that Sverdrup photographed in 1899 (1954, Vol. I, pp. 152-155), when he and Edward Bay crossed from Flagler Fiord the pass,

Fig. 7. Head of Irene Bay. The conical hill in the centre is Thumb Mountain. The western entrance to Sverdrup Pass lies immediately to the left of the mountain. August 21, 1956.

which now bears his name, and discovered the fiord named after his companion. While we were in Irene Bay we saw no ice, but the first snow of the oncoming winter fell on August 18 and persisted thereafter on the mountains (Figs. 8, 10).

On August 22 we moved back into the main part of Bay Fiord and camped opposite Mount Bell. A few pans of ice were met as we left Irene Bay but they did not obstruct travel. After a day's geological work we continued down Bay Fiord on August 24. Towards the mouth of the fiord we encountered increasingly dense bodies of pack ice and by the time we were opposite the Gretha Islands progress became impossible. Pack ice at the mouth of Bay Fiord and in Eureka Sound north of Stor Island hindered travel so much that we did not reach the north side of Vesle Fiord until August 29. It had then taken five days to make a distance of 20 miles along the coast. The first heavy snow fall and the freezing of streams came during this period: summer was clearly over in Eureka Sound. Before we entered the sound we had several opportunities to see that ice was drifting right up Bay and Strathcona fiords. Had we started our return journey a few days later it would have been far more difficult to reach Eureka Sound.

Seen from our camp in Vesle Fiord ice conditions seemed to be more favourable to the north in Eureka Sound than they had been in Bay Fiord, and we felt justified in spending three days on geological work in the neighbourhood.

Fig. 8. Looking east toward the Sverdrup Pass. The highest mountain visible on the north side of the valley is Witch Mountain (Hexefjeld). Sverdrup and Bay climbed this mountain in order to find a westward route while exploring the valley in 1899. Facing Witch Mountain may be seen the large glacier that added to their difficulties in finding a route through the pass (*See* Sverdrup, Vol. I, pp. 121, 132). August 14, 1956.

On September 1, from a camp 8 miles north of Vesle Fiord, we travelled up Eureka Sound in calm weather for about 15 miles before being stopped by a large pan of ice. This was not altogether unexpected, but we were dismayed to find that a belt of grounded floes, brash, and new ice up to 100 yards wide prevented us from reaching shore. Not until we had gone back along the coast to within a mile or so of the camp we had left earlier in the day were we able to get ashore. Safe travelling through moving pack ice in a small boat requires ready access to the shore at all times and confronted by this apparently extensive obstruction we decided to travel back to Eureka at the first opportunity, without making further stops for geological work. If the worst came to the worst, we could always walk back to the weather station, but we had about 400 pounds of geological specimens that we were loth to abandon.

Fortunately, on September 2 a moderate northeast breeze started to drive the ice in Eureka Sound over to the Axel Heiberg shore; we set off immediately and continued all the way up Eureka Sound to Slidre Fiord and the weather station. We met little moving ice until we reached Blue Man Cape; from there to Slidre Fiord considerable amounts of brash and light pack ice were encountered but they did not form an obstacle. In Slidre Fiord new ice was

forming, but we drove through it without difficulty. Within two days new and old ice had closed Slidre Fiord to canoe travel. We had clearly returned with no time to spare. By September 16 the new ice in Slidre Fiord was nine inches thick.

Between a point some ten miles north of Vesle Fiord and Blue Man Cape a nearly continuous belt of grounded and new ice prevented access to the shore. The situation was little better between Blue Man Cape and Slidre Fiord. This coastal fringe of ice was an unexpected obstruction that made it practically impossible to examine the coast, as had the shore lead during the last part of the sledging season. In four years of coastal canoeing at Cornwallis Island Thorsteinsson had never observed an ice formation of this sort on a comparable scale. This belt of coastal ice evidently originated by the filling of lagoons and interstices among large grounded polar* floes with brash ice and, at a later stage, new ice.

Between Blue Man Cape and Vesle Fiord the east side of Eureka Sound is shallow for long stretches. In places the water is less than ten feet deep up to at least 200 yards from shore, and much polar ice becomes firmly stranded in consequence. We did not experience any high winds in Eureka Sound, and this may have also been conducive to the formation of this belt of ice.

During our journey to Bay Fiord we were constantly reminded that we were following the well travelled sledge route leading to Eastern Ellesmere Island and Greenland. Although no relics of white travellers were found, old Eskimo tent rings were often seen on the shore and in Bay Fiord we found three short (about six-foot) komatik runners, one with whalebone shoeing fastened by wooden pegs. On the small point of land on the north side of the mouth of Vesle Fiord are many fox traps, of both the "box-trap" variety and also the larger igloo-shaped structures with a trap-door at the top. On the highest part of this point stands what at first sight appeared to be an unusually large igloo-shaped fox trap, but on closer examination it proved to be without an entrance. This structure is about six feet high, has a maximum diameter of about ten feet and is constructed of lichen-covered slabs of sandstone, with the top sealed by a closely fitting, pentagonal, flat rock. Removal of this slab revealed an Eskimo skeleton lying upon a platform of flat rocks. The tomb is so well constructed that little light filtered through the walls, and after a brief look we left the remains of this early Ellesmere Islander undisturbed.

Summary of geological results

Within the region investigated, rocks of Ordovician, Silurian, Pennsylvanian, Permian, Triassic, Jurassic, Cretaceous, and Tertiary age were found. The Lower Palaeozoic rocks were examined only in the inner part of Bay Fiord (including Irene Bay). The Upper Palaeozoic and Mesozoic rocks

*As defined by Armstrong and Roberts (1956, p. 8). We commonly observed grounded floes up to 20 feet thick.

were examined on Fosheim Peninsula, southwestern Grant Land and eastern Axel Heiberg Island. The information obtained may be summarized conveniently by describing, in outline, the geology of two areas: (1) Inner Bay Fiord and Irene Bay, where the Lower Palaeozoic rocks occur; (2) Western Fosheim Peninsula and southwestern Grant Land, an area characterized by Upper Palaeozoic and Mesozoic rocks. These two areas have only one formation in common—the non-marine Eureka Sound group, which according to fossil plants collected by members of "Operation Franklin" is now definitely known to include strata of Tertiary age. Throughout the entire region studied the Eureka Sound beds represent the youngest known formation. The contact between the Lower and Upper Palaeozoic rocks is not known to outcrop within the area studied, but thanks to the recent work of J. C. Troelsen it is known that an angular unconformity separates Lower and Upper Palaeozoic strata in central Canyon Fiord, a short distance east of Fosheim Peninsula. The relationship of the Eureka Sound group to the older formations in the region studied shows that the whole of Fosheim Peninsula and also the country around Bay Fiord, have suffered Tertiary orogenesis. A discussion of this relationship follows the description of the two areas. The geological account closes with a discussion of the possible extent of these Tertiary earth movements in other parts of Ellesmere Island.

Our conclusions regarding the structural history of Ellesmere Island differ from those of some of the earlier workers. It seems appropriate to summarize the conclusions of the pioneers, Per Schei, Robert Bentham and J. C. Troelsen, and also to refer to the relevant contributions by members of "Operation Franklin", before introducing our own data.

Per Schei, a member of the Second Norwegian "Fram" Expedition, was the first to describe the geology of west central Ellesmere Island. Schei collected Triassic fossils from folded rocks in Eureka Sound. He also described "Miocene sand and lignite" at various localities and he stated that the stratification of these "Miocene" rocks was undisturbed. Concerning the structural history of the Eureka Sound area Schei concluded "that the more conspicuous dislocations are post-Triassic, but pre-Miocene" (Schei, in Sverdrup, 1904, Vol. II, p. 463).

Robert Bentham (1941) made some important observations concerning southern Ellesmêre Island, for he suggested that faulting had taken place after the deposition of Schei's "Miocene" beds. Bentham's views anticipate our own to a considerable extent.

J. C. Troelsen was the next geologist to make field observations in this area. In 1950 he published a report (Troelsen, 1950) based on his work as geologist of the 1939-1940 Van Hauen Expedition. He showed that gently folded Pennsylvanian and Permian rocks occur in Canyon Fiord, overlain conformably by strata believed to be possibly of Jurassic age (Cape With formation). He also described folded Ordovician and Silurian rocks in the upper part of Bay Fiord. Troelsen concluded that Ellesmere Island has been

subjected to orogenesis twice since the Precambrian: once in the Palaeozoic, prior to the deposition of the Pennsylvanian rocks and again in the Mesozoic or Cenozoic. Troelsen's Mesozoic or Cenozoic orogeny is the same as Schei's post-Triassic, pre-Miocene deformation. Troelsen's rather more elastic dating of the younger orogeny reflects his conclusion that Schei's "Miocene" strata (named the Eureka Sound group by Troelsen) could be of Cretaceous or Tertiary age.

In 1952 Troelsen returned to Ellesmere Island and demonstrated conclusively that a conspicuous angular unconformity separates Silurian and Middle Pennsylvanian rocks at "Caledonian Bay" in Canyon Fiord (Troelsen, 1952). On this occasion he also discovered folded late Jurassic-Early Cretaceous beds with *Aucella*, and other fossils, near Eureka weather station. In a MS account submitted to the Arctic Institute of North America in February 1954, Troelsen records fossil identifications by C. W. Wright and J. A. Jeletzky that show his collections to be of early Lower Cretaceous age. Following his field work of 1952, Troelsen's conclusions regarding the tectonic history of west central Ellesmere Island can be summarized as follows: the earlier orogeny took place in "post-Silurian (or possible late Silurian) but pre-Middle Carboniferous" (Middle Pennsylvanian) time; and the younger orogeny, involving Pennsylvanian, Permian, Triassic and Lower Cretaceous rocks, took place before the deposition of the Eureka Sound group.

It should be mentioned that Schei and Troelsen did not describe an unconformable contact between the Eureka Sound beds and the folded Mesozoic rocks. Their conclusion that such an unconformity existed was based solely upon the apparent absence of folds in the Eureka Sound group comparable with those shown by the Mesozoic rocks.

Two members of "Operation Franklin" obtained additional data on the Eureka Sound beds. N. J. McMillan collected fossil plants on north-western Fosheim Peninsula which have been examined by W. L. Fry of the Geological Survey of Canada. Fry considers that the plants from Fosheim Peninsula are of Tertiary, and probably of early Tertiary (Palaeocene or Eocene) age. A. W. Norris studied the Eureka Sound beds near Vendome Fiord. Both McMillan and Norris noted that the Eureka Sound beds had been folded and concluded, contrary to the opinions of Schei and Troelsen, that the Eureka Sound group does not constitute a simple post-orogenic formation. Unfortunately, the base of the Eureka Sound group is not exposed in the areas studied by McMillan and Norris so that the relation to the older folded rocks could not be determined.

Inner Bay Fiord and Irene Fiord

Rocks of Ordovician, Silurian and possibly Devonian age, and also the Eureka Sound group, were studied in Irene Bay and in inner Bay Fiord. After examining the maps prepared by Schei and Troelsen we had expected to find

Precambrian rocks exposed in this region and perhaps also the basal Palaeozoic strata. The shores of Irene Bay, however, are composed entirely of Palaeozoic and Eureka Sound rocks.

The Ordovician and Silurian rocks of this area resemble rather closely those described on Cornwallis Island by Thorsteinsson (1955).

Fig. 9. Lower Palaeozoic and Eureka Sound beds north of Irene Bay. The light coloured country is composed of Ordovician and Silurian limestone and dolomite (Cornwallis and Allen Bay formations). The dark terrain represents the Eureka Sound formation. The small stream in the foreground follows the contact between the Lower Palaeozoic and Eureka Sound rocks. This contact is inclined to the west and the bedding in the Palaeozoic and Eureka Sound rocks is essentially parallel, as shown by the structure section No. 2, Fig. 12. August 14, 1956.

Three Cornwallis Island formations can be recognized. The Ordovician Cornwallis formation outcrops both east and west of Irene Bay. It is at least 4,300 feet thick and consists mainly of limestone with a unit of gypsum beds in the lower part. At the top of this formation occurs the member containing the "Arctic Ordovician fauna", as in the type section. The Ordovician and Silurian rocks overlying the Cornwallis formation are of two facies, graptolitic and non-graptolitic. The boundary between the two facies lies about five miles west of Irene Bay and apparently trends northeast. The graptolitic beds lie to the west of this boundary and the non-graptolitic rocks to the east. The actual boundary lies within a syncline occupied by younger gypsiferous beds and so is not exposed (Fig. 11). The non-graptolitic rocks consist of unfossili-

ferous dolomite, similar to the Allen Bay formation of Cornwallis Island. The graptolitic beds are mainly shale with some limestone, and contain Ordovician and Silurian graptolites that permit a close correlation with the Cape Phillips formation of Cornwallis Island. A trilobite zone that occurs in the basal Cape Phillips strata of one section evidently represents the Thorup Fiord Limestone, described by Troelsen (1950, p. 59). The Read Bay formation (Silurian) of Cornwallis Island is not present in the section examined around the head of Bay Fiord, for both the Allen Bay and Cape Phillips formations are succeeded by 1,800 feet of green and red gypsum measures which are overlain by at least 900 feet of unfossiliferous dolomite. The age of the gypsum and overlying dolomite cannot be determined at present but they are certainly younger than mid-Upper Silurian (Middle Ludlow) on the basis of graptolites present in the underlying Cape Phillips formation. Possibly they are of Devonian age or even younger.

Around Irene Bay and inner Bay Fiord are extensive exposures of non-marine coal-bearing beds that represent the Eureka Sound group. These beds overlie, without noticeable unconformity, both the Allen Bay and Cornwallis formations (Figs. 9, 12). In many places the Eureka Sound and underlying rocks are quite steeply inclined (up to 40 degrees). However, the bedding of the Eureka Sound and Palaeozoic rocks is roughly parallel, although the boundary is, of course, disconformable as there occur no rocks representing Upper Palaeozoic and Mesozoic times. Perhaps this boundary should be described

Fig. 10. Mountains of Lower Palaeozoic limestone and dolomite west of Irene Bay. Section No. 1, Fig. 11, illustrates the structure of this range. The low country in the foreground is adjacent to the shore of Irene Bay and is underlain by soft strata of the Eureka Sound group. A fault, probably a thrust fault, lies between the Lower Palaeozoic and Eureka Sound rocks. August 21, 1956.

as a mild angular unconformity, for as shown in Fig. 12, the thickness of Allen Bay strata beneath the Eureka Sound beds is greater on the west side of Irene Bay than on the east. Furthermore, formations younger than the Allen Bay formation appear a short distance west of Irene Bay (Fig. 11). In the Irene Bay area the Eureka Sound beds were presumably deposited upon a terrain dipping gently to the west and formed by the Allen Bay and younger formations.

The Lower Palaeozoic rocks, together with the essentially conformable overlying layer of Eureka Sound beds have been folded and faulted. The strike of both folds and faults is about northeast. Most of the faults that dislocate the strata have upthrow sides to the west and they are believed to represent thrust faults (Figs. 11, 12). This faulting is very prominently expressed in the topography of inner Bay Fiord and Irene Bay, for the Lower Palaeozoic rocks form mountainous ridges and the synclines and downfaulted areas of Eureka Sound rocks form the wide valleys and rolling hills. The contrasting geology is conspicuously reflected in the nature of the vegetation (Figs. 9, 10). The lowlands formed by the Eureka Sound rocks are exceptionally well vegetated; the Palaeozoic limestone and dolomite areas, as in so many parts of the Arctic Archipelago, are almost, to quite barren.

The discovery that the Palaeozoic and Eureka Sound beds are folded together at the head of Bay Fiord places the age of deformation in the Tertiary period. This result was quite unexpected, for Troelsen (1950, p. 25) believed that the inclined attitude of the Lower Palaeozoic rocks in this area was due to Palaeozoic earth movements.

Western Fosheim Peninsula and southwestern Grant Land

Field work on Fosheim Peninsula, west of the "Sawtooth Range" and in southwestern Grant Land has revealed a structurally conformable sequence of Pennsylvanian, Permian, Triassic, Jurassic, Lower Cretaceous, Upper Cretaceous and Tertiary rocks. The Tertiary rocks belong in the Eureka Sound group. The sequence recognized in southwestern Grant Land ranges from Pennsylvanian to Triassic and that of Fosheim Peninsula from Permian to Tertiary. The "Miocene" rocks described by Schei (*in* Nathorst, 1915, p. 7) in Grant Land (west of Blue (Blaa) Mountain) are placed in the Triassic by the writers. Gabbro sills occur in the Pennsylvanian, Permian and Triassic formations, and they are thickest and most abundant in the Triassic. This whole sequence has been folded, in places quite severely. South of Greely Fiord fold axes generally trend northerly. North of Greely Fiord they commonly trend northeasterly. Much faulting is associated with this deformation. Most of the faults parallel anticlinal axes, and most (but not all) have their upthrow side to the west or northwest. It therefore seems probable that they, like the structures in Irene Bay, represent thrust faults.

The Pennsylvanian and Permian rocks include limestone, shale, chert, and sandstone. The facies relationships are apparently complex and cannot be

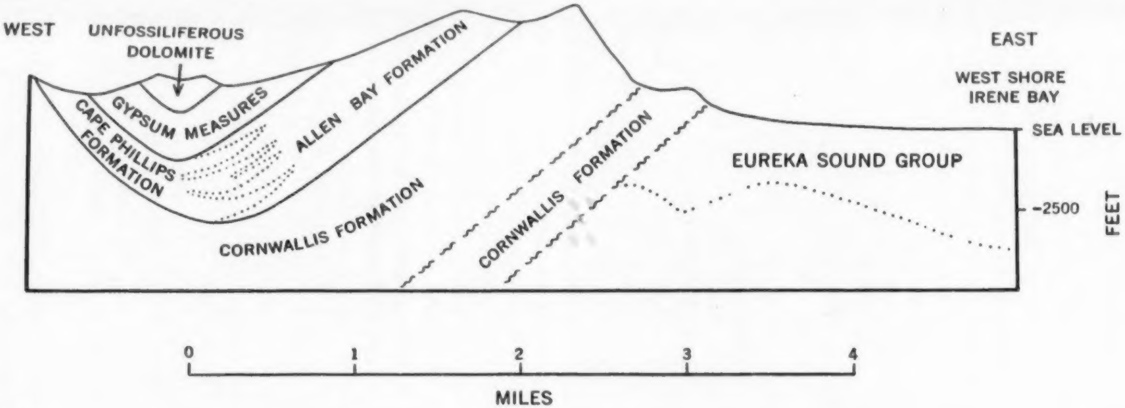


Fig. 11. Structure section No. 1. Position of section is shown on map, Fig. 1.

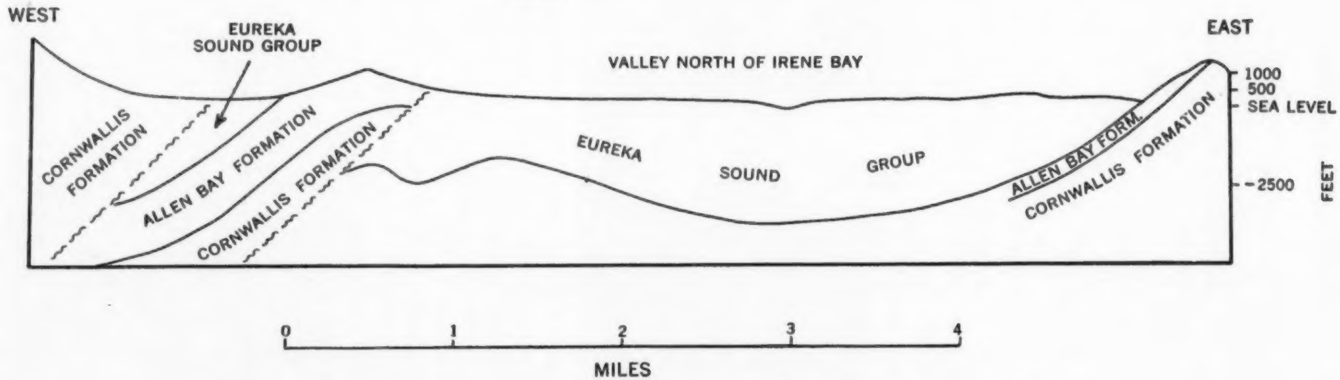


Fig. 12. Structure section No. 2. Position of section is shown on map, Fig. 1.

adequately treated here. Of particular interest is a unit of gypsum with some interbedded limestone, in all about 700 feet thick, which occurs within the Pennsylvanian-Permian sequence in the upper reaches of Hare Fiord and on the peninsula between Borup and Hare fiords. Northeast of the entrance to Hare Fiord the bedded gypsum, when traced along strike, develops into an intrusive piercement body, in which the gypsum has been forced upward to come into contact with rocks that normally are separated from it in the stratigraphic section. At Fair Cape, on the east coast of Axel Heiberg Island, contorted strata of gypsum and limestone, closely resembling the gypsum measures of Hare and Borup fiords, form the core of a piercement anticline. In this structure the gypsum has pierced the overlying sedimentary layers and is in contact with Upper Triassic rocks. It seems reasonable to conclude that this gypsum represents the same formation that has provided the gypsum in the cores of piercement structures in the Ringnes Islands (Heywood, 1954; Fortier *et al.*, 1954) and other parts of the Archipelago.

The Mesozoic rocks of western Fosheim Peninsula and adjacent regions to the north include an aggregate thickness of about 20,000 feet of strata. Sandstones and shales are the most common rocks and both marine and non-marine deposits are present. Relatively coarser detritus is found to the east, in the foothills of the "Sawtooth Range", and there can be no doubt that the source of most of the Mesozoic sediment lay in that direction.

Marine deposits of Lower, Middle, and Upper Triassic age were found. Troelsen's Cape With formation (Troelsen, 1950, p. 75) of the "Sawtooth Range", formerly of uncertain age, has yielded Triassic ammonites (*Nathorstites*). This formation is believed to represent a sandy facies of the finer grained Triassic rocks (Blaa Mountain formation) described by Per Schei and Troelsen farther west in Eureka Sound. The youngest Triassic rocks are mainly sandstones and include non-marine strata with thin coal seams. They are overlain by a sequence of Jurassic rocks of partly marine, but mainly of non-marine origin. Above this Jurassic formation lies the Deer Bay shale, which was originally described on Ellef Ringnes Island by Heywood (1954). The lower part of the Deer Bay formation contains Upper Jurassic ammonites; higher beds contain *Aucella* and ammonites of early lower Cretaceous age. It was from this formation that Troelsen (1952, p. 208) collected *Aucella*. The succeeding Cretaceous rocks consist of alternating marine and non-marine formations. Above the Deer Bay shale is the non-marine Isachsen formation, composed mainly of sandstones; then the marine Christopher shale of late Lower Cretaceous age; next another non-marine sandstone which is followed by a marine Upper Cretaceous shale with distinctive representatives of the pelecypod genus *Inoceramus*. The Isachsen and Christopher formations, like the Deer Bay, were originally defined on Ellef Ringnes Island by Heywood. The succeeding non-marine sandstone and the Upper Cretaceous shale have not yet been formally named.

Above the Upper Cretaceous shale there follows, apparently in perfect conformity, a thick sequence of non-marine beds, with several seams of coal

up to six feet thick and fossil plants of Tertiary age (Fig. 13). These are the beds (Eureka Sound group) that Schei and Troelsen considered to have been deposited after the folding of the Mesozoic rocks. All the evidence we have found in western Fosheim Peninsula indicates that the Eureka Sound group was folded at the same time as the underlying Mesozoic rocks. A structure section across Fosheim Peninsula (Fig. 14) illustrates this relationship. In Western Fosheim Peninsula the Eureka Sound beds are apparently confined to synclines; nowhere have they (or any similar rocks) been found resting on truncated folds of Mesozoic strata.

Fig. 13. Dark coloured marine Upper Cretaceous shale (to the right) overlain by sandstone, shale, and coal beds of the Eureka Sound group (to the left). Both formations are dipping to the east and are apparently perfectly conformable. This section is exposed along "Remus Creek", immediately east of "Black Top Ridge". August 5, 1956.

Relationship of the Eureka Sound group to the underlying formations in west central Ellesmere Island

The rocks that underlie the Eureka Sound group in Irene Bay are much older than those immediately beneath the group on Fosheim Peninsula, namely, of Ordovician and Silurian age in Irene Bay and of Upper Cretaceous age on Fosheim Peninsula. Despite the great difference in age of the rocks beneath the Eureka Sound group in these two areas, the contact with the underlying rocks is essentially conformable in each area. Throughout the entire region under consideration the Eureka Sound and underlying rocks have been folded and faulted. The earth movements responsible for these structures clearly post-date the Eureka Sound beds and are, therefore, of Tertiary age.

From what has been said in the preceding paragraph it might be supposed that the only earth movements that have affected west-central Ellesmere Island took place in Tertiary time. This, however, is not so, for Troelsen (1952)

has described a substantial unconformity between Middle Pennsylvanian and Silurian rocks at "Caledonian Bay" in central Canyon Fiord. Troelsen has thus proved that a belt of Lower Palaeozoic rocks in central Canyon Fiord was severely affected by Palaeozoic earth movements, unlike the contemporary strata of Irene Bay. The Palaeozoic fold belt of Canyon Fiord presumably extends southward and crosses Bay Fiord west of Irene Bay*. Rocks of this belt do not outcrop on the north coast of Bay Fiord. Where exposures of this Palaeozoic fold belt might be expected, namely in the central part of Bay Fiord, gently folded Eureka Sound beds conceal all older rocks. Nevertheless, the belt of Palaeozoic orogeny and its boundary with the rocks not deformed in Palaeozoic time presumably occurs beneath this cover in central Bay Fiord. Central Bay Fiord is within the area of Tertiary deformation and it therefore follows that in this area the belt of Tertiary orogeny is superimposed upon the region of Palaeozoic orogeny. As the inner part of Bay Fiord has been affected only by Tertiary movements it appears that the "front" of the Tertiary orogeny lies farther to the east than that of the Palaeozoic orogeny. Nothing definite is known of the western limit of the Palaeozoic fold belt.

Apparently the geology of the surface beneath the Eureka Sound group is very varied, for the group seems to overstep progressively, from west to east, first the conformable Upper Palaeozoic-Mesozoic section, then the belt of Palaeozoic rocks folded before Middle Pennsylvanian time, and it finally rests upon Lower Palaeozoic rocks unaffected by the Palaeozoic orogeny†. This partly hypothetical explanation of the relationship between the Eureka Sound and older formations is shown diagrammatically in Fig. 15, which portrays the supposed relationship prior to the Tertiary orogeny.

This explanation calls for the appearance of an unconformity between the Upper Palaeozoic-Mesozoic section and the Eureka Sound group in the area east of "Sawtooth Range". This unconformity, considered over a wide area, presumably constitutes a gentle angular discordance of the type that would probably not be visible at a single outcrop. Epeirogenic movements and erosion that took place east of "Sawtooth Range" prior to the deposition of the Eureka Sound group probably have produced such an unconformity.

In addition to epeirogenic movements of this sort, two other factors may have facilitated the Eureka Sound overstep illustrated in Fig. 15. First, the Upper Palaeozoic and Mesozoic formations apparently thin considerably when traced from west to east. Secondly, some (or all) of the Upper Palaeozoic and Mesozoic formations that underlie the Eureka Sound beds of western Fosheim Peninsula may not have been deposited as far east as Irene Bay. Both these factors would decrease the amount of erosion necessary to account

*At Troll Fiord, Tozer noted also an unconformity between the Pennsylvanian and Permian rocks, which may further complicate the geology of the surface beneath the Eureka Sound beds.

†Field work by Tozer on "Operation Franklin" revealed an unconformity identical with Troelsen's at the head of Troll Fiord, some 20 miles south of Bay Fiord. This confirms that the Canyon Fiord Palaeozoic fold belt extends to the south and crosses Bay Fiord.

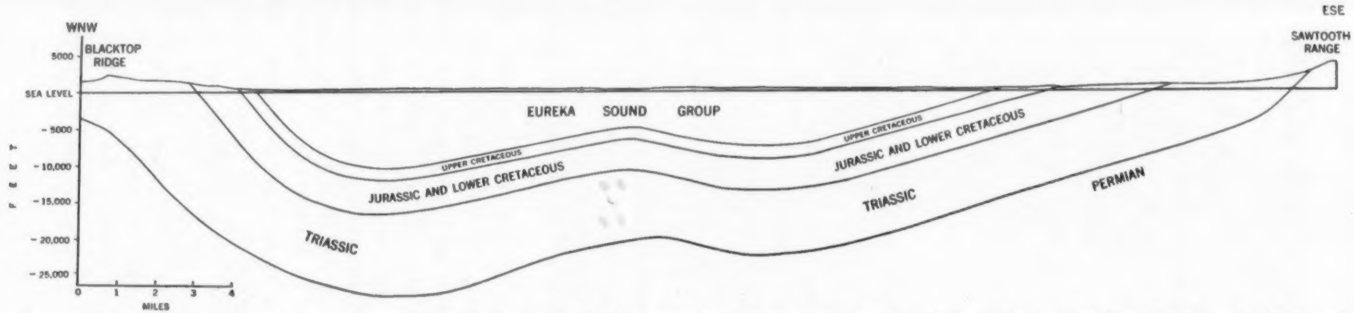


Fig. 14. Structure section No. 3, across northern Fosheim Peninsula from "Sawtooth Range" to "Blacktop Ridge". Position of section is shown on map, Fig. 1.

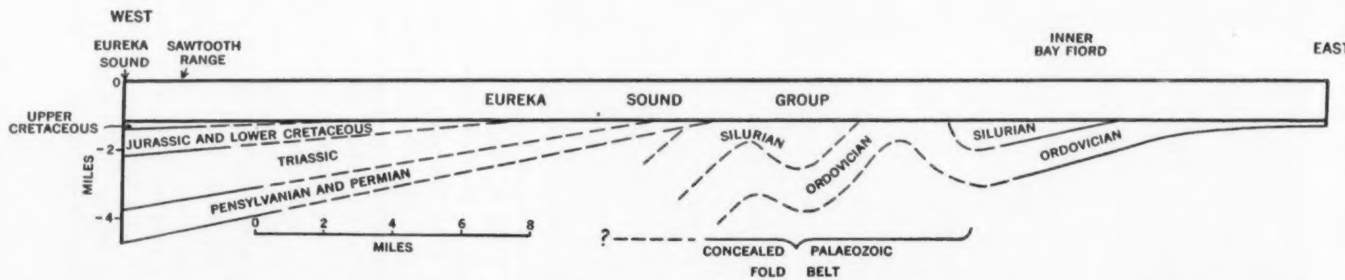


Fig. 15. Diagram showing supposed relationship of Eureka Sound group to older formations in west central Ellesmere Island, at the latitude of Bay Fiord. The section shows the relationship prior to the Tertiary orogeny. Solid lines illustrate established relations; dashed lines represent hypothesis.

for the present day situation of the Eureka Sound beds in the inner Bay Fiord and Irene Bay area. The original eastern limit of these Upper Palaeozoic and Mesozoic formations is not known, but as the Mesozoic sediments of Fosheim Peninsula were apparently derived from the east (see above), it is possible that in Mesozoic (and perhaps also Upper Palaeozoic) time parts of eastern Ellesmere Island constituted a low lying source of sediment rather than a site of deposition.

Regional extent of Tertiary orogeny in central and northern Ellesmere Island

It has been shown that the younger orogeny of Fosheim Peninsula is of Tertiary age and that the entire region between Eureka Sound and Irene Bay has been affected by these movements.

The southwestern part of Grant Land has clearly been involved in the same orogeny, as recognized by Troelsen (1950, p. 17). Our own observations in this area show that the fold axes swing from north to northeasterly, and from the head of Borup Fiord the axes are directed northeastward towards the mountains of central Grant Land and the United States Range. The course of Hare Fiord follows this structural trend and illustrates the change in strike. Troelsen (1950, p. 32) suggested that the mountains of Grant Land might represent an area affected by the younger orogeny and the evidence from Borup and Hare Fiords certainly supports that view.

It also seems probable that much of the mountainous terrain of eastern Ellesmere Island was deformed in Tertiary rather than Palaeozoic time. This suggestion probably applies to the mainly ice covered Victoria and Albert Mountains, that lie between Copes Bay and Canyon Fiord, and also to the fold mountains of Judge Daly Promontory, southeast of Archer Fiord (Fortier *et al.*, 1954, p. 205). Air photographs of these ranges show that they are perfectly on strike with the northeasterly trending structures of Irene Bay.

It is not intended to suggest that the whole of northeastern Ellesmere Island was affected by Tertiary orogeny; on the contrary, there is some evidence from air photographs to indicate that the Greely-Hazen Plateau was not affected by these movements. This remarkable plateau lies between the Victoria and Albert Mountains and the great ranges of Grant Land. It extends from the upper reaches of Greely Fiord across to Archer Fiord on the east coast of Ellesmere Island. Lake Hazen lies near its northern boundary. Air photographs (Fig. 16) of the peninsula between Greely and Tanquary fiords, which represents the western part of this plateau, reveal extensive patches of flat-lying strata resting upon a peneplained surface of highly deformed rocks. Two geologists, Ekblaw in 1915 and Troelsen in 1940, passed through this country, long before the air photographs were taken. Troelsen (1950, p. 63) mapped highly folded rocks at the head of Greely Fiord as the Cape Rawson formation (Precambrian or Palaeozoic). Between the mouth of Tanquary

Photo: R.C.A.F.

Fig. 16. Tanquary Fiord, northern Ellesmere Island. In the foreground, southeast of the fiord, is the west end of the Greely-Hazen plateau. The flat-topped hills in this area are believed to represent unfolded outliers of Permian rocks. Topographically and stratigraphically below the supposed Permian rocks may be seen the steeply inclined beds that evidently represent the Precambrian or Paleozoic Cape Rawson formation. The mountainous country in the background, northwest of Tanquary Fiord, is on strike with the folded Pennsylvanian and Permian rocks of Borup, Hare, and Otto fiords. The plateau in the foreground apparently was not affected by Tertiary folding, unlike the mountainous country behind.

Fiord and the head of Greely Fiord he described gently dipping Permian rocks. Although he did not see the contact, Troelsen concluded that an unconformity separated the Cape Rawson and Permian rocks, and that the folding of the older rocks took place in Palaeozoic time. The air photographs certainly support Troelsen's contention that an unconformity is present near the head of Greely Fiord. There seems to be little doubt that the flat-lying rocks on the air photographs of the west end of the Greely-Hazen Plateau represent

outliers of Permian (and possibly also Pennsylvanian) rocks resting unconformably upon the intensely folded Cape Rawson beds (Fig. 16). If the undisturbed rocks are of Pennsylvanian or Permian age, the Greely-Hazen Plateau, although probably folded in Palaeozoic time, was not deformed during the Tertiary orogeny that affected the areas to the northwest and southeast. In other words, the most extensive plateau area of northern Ellesmere Island may represent a region unaffected by Tertiary earth movements that is flanked by mountainous areas affected by Tertiary orogeny.

Our conclusions regarding the later structural history of central and northern Ellesmere Island may be summarized as follows.

(1) On Fosheim Peninsula, in southwestern Grant Land, and in Bay Fiord, structural deformation took place in Tertiary time, after the deposition of the strata known as the Eureka Sound group.

(2) In west central Ellesmere Island, no deposits (other than of Pleistocene and Recent age) have been found that are younger than this orogeny.

(3) The belt of Tertiary orogeny extends farther to the east than the older, Palaeozoic, orogenic belt.

(4) Probable extensions of this Tertiary orogenic system occur in central Grant Land and on Judge Daly Promontory.

(5) Evidence from air photographs suggests that the Greely-Hazen Plateau, although flanked by Tertiary fold belts, was not deformed in Tertiary time.

(6) The areas of Tertiary orogeny in central and northern Ellesmere Island seem to correspond to the regions of greatest relief and physiographic immaturity.

Appendix. Notes on wildlife

Eureka has been visited by several zoologists: J. S. Tener in 1951, P. F. Bruggemann in 1953 and 1954, and by S. D. MacDonald and D. Parmelee, both in 1955. To date the only publication that has appeared on the wildlife of the area is the report by Tener (1954), which concerns the musk ox. A complete list of the known mammals and birds will probably soon be published by MacDonald. Although we have no pretensions as zoologists the following notes are offered to supplement the observations of the various specialists mentioned above because these notes include information on many areas not visited by them.

Wolf: Judging from the number of tracks seen, wolves are fairly common throughout the region visited. A total of 19 animals was seen.

Fox: Tracks of arctic fox were common but fewer than ten animals were seen.

Weasel: Tracks of two weasels, but no animals, were seen.

Polar bear: Bears are apparently rare throughout the region. Tracks (possibly of one and the same animal) were seen south of Skraeling Point and in Hare Fiord. A single animal was seen in Vesle Fiord, on September 1.

Ringed seal: Seals were first seen sleeping on the ice in Borup Fiord, on May 11. Thereafter they became increasingly abundant in Greely, Hare and Canyon fiords. By early June we generally saw up to ten a day in these areas. When we travelled down Eureka Sound in August the density of the seal population seemed to increase towards Bay Fiord. In August, 19 seals were seen resting on a single large ice pan just north of Vesle Fiord. In this area we usually had two or three seals around the camp and the canoe.

Musk ox: It is well known that musk oxen are abundant on Fosheim Peninsula. Sizable herds were also seen in Borup Fiord, Hare Fiord, near the mouth of Otto Fiord, near East Cape, west of Skraeling Point and in the Bay Fiord region. Our total count for the season was 278 animals, of which at least 61 were calves. The count of calves represents a minimum figure as the total includes animals seen too far away to distinguish adults from young. It seems to have been a good year for the musk oxen: two herds were seen each of which comprised 12 adults and 8 calves.

Caribou: Caribou are evidently very rare in the region visited. Nine animals were seen near East Cape and tracks attributed to very small herds were seen at Butter Porridge Point, Vesle Fiord, and Slidre Fiord.

Hare and lemming: Hares were abundant wherever we went and lemmings occurred in prodigious numbers this year.

Loon: About ten red-throated loons were seen during the season.

Eastern brant: On June 16 one pair of brant was seen on the north coast of Nansen Sound between Otto and Hare fiords, where they were feeding with snow geese.

Snow goose: A very common nesting species throughout the region visited. The first pair was seen in Hare Fiord, on May 31. Several nests were found and broods, generally comprising five young, were noted in July. An estimated 200 snow geese were seen in Irene Bay and inner Bay Fiord, of which more than half were young. In 1955 several flocks of adult snow geese were seen in central Ellesmere Island and on the west coast of Axel Heiberg Island, but they were seldom accompanied by young. This year only one flock was seen without young.

King eider and old-squaw: Both species were first seen on July 1, at Iceberg Point, and from then on they were common.

Gyrfalcon: On August 9 a gyrfalcon nest was found on a low cliff near the coast of Eureka Sound, about 9 miles east of Blue Man Cape. The family included two young, fully fledged but barely able to fly. Another group of four was noted near the head of Bay Fiord. In September gyrfalcons descended upon the weather station in force. At one time there were 11 individuals perched on the antenna masts and wires.

Ptarmigan: Ptarmigan are fairly common residents. They were only rarely seen in the spring and during the nesting season, but several broods of up to 13 young were encountered during the last week of August and in early September.

Knot and ruddy turnstone: These two shore birds are probably the most common nesting species in the region. Both were first sighted in the pass between Hare and Otto fiords on May 13.

Jaeger: Long-tailed jaegers are a very common nesting species throughout the region; the first were seen in Hare Fiord on June 4. Parasitic jaegers are relatively rare. Only six were seen during the season.

Thayer's gull: Gulls tentatively identified as this species were first sighted at Degerböls Island in Otto Fiord on June 3. During the season about 15 of these birds were seen.

Glaucus gull: About 25 gulls, almost certainly this species, were seen near Thumb Mountain at the head of Irene Bay.

Arctic tern: Terns were first seen at Iceberg Point on July 1. They were very common after that date. Apparently they nest in great numbers on the small islet at the mouth of Vesle Fiord.

Snowy owl: About 30 owls, including three broods, were observed during the season.

References

(Arctic Circular) 1954. Police patrols to Axel Heiberg and Devon islands. Arctic Circular 7: 34-6.

Armstrong, Terence and Brian Roberts. 1956. Illustrated ice glossary. Polar Record 8: 4-12.

Bentham, Robert. 1941. Structure and glaciers of southern Ellesmere Island. Geog. J. 97: 36-45.

Blackadar, R. G. 1954. Geological reconnaissance north coast of Ellesmere Island, Arctic Archipelago, Northwest Territories. Geol. Surv., Can., Paper 54-10, 22 pp. and map.

Christie, R. L. 1955. Geological observations, 1954, *in* Hattersley-Smith, 1955.

Fortier, Y. O., A. H. McNair, and R. Thorsteinsson. 1954. Geology and petroleum possibilities in Canadian Arctic Islands. Am. Assoc. Petrol. Geol., Bull. 38: 2075-109.

Hattersley-Smith, G., *et al.* 1955. Northern Ellesmere Island, 1953 and 1954. Arctic 8: 3-36.

Heywood, W. W. 1954. Arctic piercement domes. Can. Inst. Min. & Met., Trans. 58: 27-32.

MacMillan, D. B. 1918. Four years in the white North. New York: Harper & Brothers. xiii + 415 pp.

Nathorst, A. G. 1915. Tertiäre Pflanzenreste aus Ellesmereland. Rept. Second Norwegian Exp. in the "Fram", 1898-1902, No. 35, 16 pp.

Porsild, A. E. 1955. The vascular plants of the western Canadian Arctic Archipelago. Natl. Mus. Can., Bull. 135, 226 pp.

Sverdrup, Otto. 1904. New land; four years in the arctic regions. London: Longmans, Green, Vol. I, xvi + 496 pp.; Vol. II, 504 pp.

Tener, J. S. 1954. A preliminary study of the muskoxen of Fosheim Peninsula, Ellesmere Island, N.W.T. Can. Natl. Parks Br., Wildlife Mngt. Bull., Ser. 1., No. 9, 34 pp.

Thorsteinsson, R. 1955. Geology of Cornwallis and Little Cornwallis islands, Arctic Archipelago, Northwest Territories. University of Kansas: unpublished Ph.D. thesis. (Geol. Surv., Can., Mem. 294, in press).

Thorsteinsson, R. and Y. O. Fortier. 1954. Report of progress on the geology of Cornwallis Island, Arctic Archipelago, Northwest Territories. Geol. Surv., Can., Paper 54-24, 25 pp. and map.

Tozer, E. T. 1956. Geological reconnaissance, Prince Patrick, Eglinton, and western Melville islands, Arctic Archipelago, Northwest Territories. Geol. Surv., Can., Paper 55-5, 32 pp. and map.

Troelsen, J. C. 1950. Contributions to the geology of northwest Greenland, Ellesmere and Axel Heiberg islands. Medd. om Grønland, 149, No. 7: 1-86.

——— 1952. Geological investigations in Ellesmere Island, 1952. Arctic 5: 199-210.

Vibe, Christian. 1948. Langthen og nordpaa, Skildringer fra "Den Danske Thule- og Ellesmereland-ekspedition 1939-40". Copenhagen: Gyldendal, 199 pp. and map.

THE ROLLS ON THE ELLESMERE ICE SHELF*

G. Hattersley-Smith†

IN A paper on arctic ice islands (Koenig *et al.*, 1952) it was pointed out that surface rolls are characteristic features of both the Ellesmere Ice Shelf and the floating ice islands. From this it was inferred that the ice islands almost certainly originated by calving from the Ellesmere Ice Shelf. The shape of one large ice island did in fact prove its former contiguity with the ice shelf off the mouth of Markham Bay. Comparison of roll patterns of other ice islands with the roll pattern on the ice shelf may indicate the exact areas from which the ice islands have calved. It is therefore of interest to discuss the origin and evolution of these surface features.

*This paper, which forms one chapter of an unpublished thesis, is published by permission of the Chairman, Defence Research Board of Canada.

†Geophysics Section, Defence Research Board of Canada.

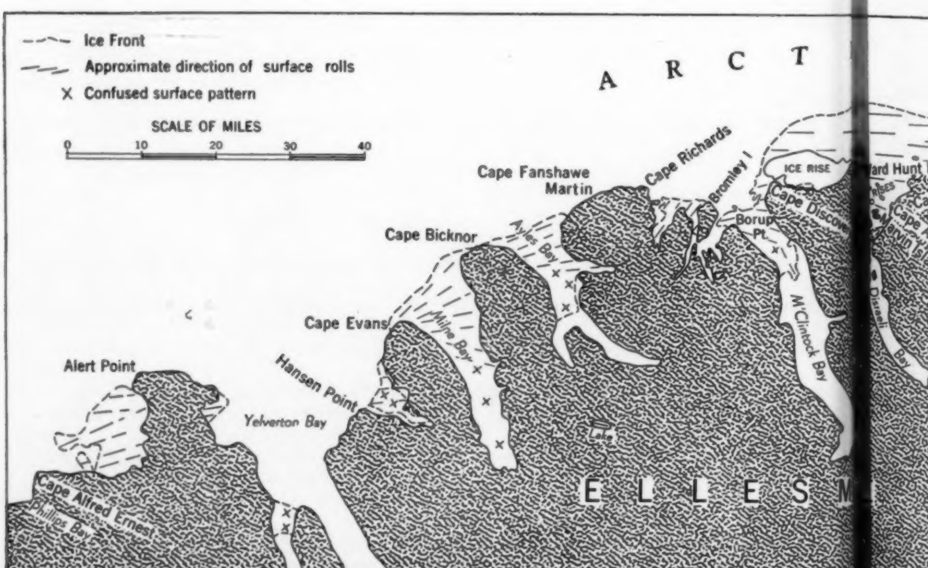


Fig. 1. Sketch map of th ern Elle

The ridges and troughs that constitute the rolls on the surface of the Ellesmere Ice Shelf (Hattersley-Smith *et al.*, 1955, p. 12) show a general parallelism to the outer coast, but inside the fiords they tend to swing southward or to become disorganized (Fig. 1). In 1954 a transit level survey was carried from the mainland shore to the ice front on a south-north line, one mile west of Ward Hunt Island ice rise (Crary *in* Hattersley-Smith *et al.*, 1955, p. 27); the results of the survey are shown in Fig. 2, in which the vertical scale has been greatly exaggerated. The greatest difference in elevation between the bottom of a trough and the crest of an adjacent ridge was observed to be 21.2 feet, with allowance for the different amounts of snow at the two places.

Since the ice shelf is floating and in isostatic equilibrium, it may be expected to be proportionately thinner beneath the troughs and thicker beneath the ridges. The difference in thickness beneath a trough and an adjacent ridge should be equal to more than the difference in elevation between the bottom of the trough and the crest of the ridge, for it seems unlikely that the rigidity of the ice is sufficient to support a ridge and trough pattern on the surface without a reciprocal pattern on the underside. The tendency of the ice islands to break off from the ice shelf along lines parallel to the ridges and troughs may be due to the fact that the troughs, where the ice shelf is thinner, are lines of structural weakness (cf. Koenig *et al.*, 1952, p. 81).

of t ern Ellesmere Island.

The ice thicknesses obtained seismically near the edge of the ice island T3 give some indication of rolls on the under surface; the convex-upward troughs on the under surface seem to be vertically beneath the troughs on the upper surface (Crary, 1954, p. 300). Robin (1954, p. 200) has postulated similar conditions for the Maudheim Ice Shelf in western Dronning Maud Land. The effect of isostatic forces on a mass of floating ice of irregular thickness has been demonstrated by Russian work. Thus "a hummock was demolished on an ice field to the north of Laptev Sea in the preparation of an airdrome. After several days, a bulge appeared at the place of the razed hummock as a result of isostacy, ruining the airdrome." (Zubov, 1938, p. 11).

The temperature of the lower surface of the ice shelf is between -2° and -3°C., according to the salinity of the water. The temperatures measured in the ice shelf (Crary, *in* Hattersley-Smith *et al.*, 1955, p. 30) indicate a considerable temperature gradient from the lower to the upper parts of the shelf. Heat flows from the water to the ice. If the water is above its freezing point, the transfer is accompanied by freezing (Simpson, *in* Debenham, 1948, p. 213). There should be less melting and more freezing beneath the troughs, where the ice shelf is thinner, than beneath the ridges. Rolls on the under-surface should therefore tend to be flattened out. It must be assumed that this tendency is more than offset by the isostatic effect resulting from the deepening of the surface troughs by melt-water, whose warming effect persists throughout the winter, as shown by the higher ice temperatures beneath a trough (Crary, *in* Hattersley-Smith *et al.*, 1955, p. 30). The increase in the depth of the troughs toward land is due partly to increased melting near land, and hence to a greater flow of melt-water. Two other factors may also be partly responsible for the greater depth of the troughs on the landward part of the ice shelf—the greater thickness of the shelf, giving the trough rivers and lakes a higher gradient and a faster flow toward the tidal cracks draining to the sea; the probably greater age of this part of the shelf, which has allowed more time for the troughs to develop.

Secondary troughs near the crests of some of the major ridges suggest that modification of the primary drainage pattern may have taken place from time to time. Modification could be due to blocking of drainage channels and filling up of some troughs by lake ice or it could be due to melt-water overflowing from the trough lakes to form new lakes in depressions on the ridges. The general shallowness of the troughs on the ice islands T1 and T2, as seen in air photographs (Koenig *et al.*, 1952, pp. 70, 72), may perhaps be due to filling by lake ice since the time when the ice islands broke away from the ice shelf. In a trough lake on T3 blockage of outlet led to an increment of 35 inches of ice (Goldstein, *in* Crary *et al.*, 1955, No. 8, p. 3).

Undulations have also been described near the seaward edges of antarctic ice shelves (Wright and Priestley, 1922, p. 208; Siple, 1945, p. 57; Debenham, 1948, p. 210; [Roscoe], 1953, p. 58; Swithinbank, 1955, p. 72). On the relatively thin Ellesmere Ice Shelf the rolls have a shorter wave length than the

undulations on the much thicker antarctic ice shelves, as the following figures show. In the vicinity of Ward Hunt Island (Koenig *et al.*, 1952, p. 66), where the thickness of the ice shelf is at the most 120 to 150 feet, the ridges are 200 to 300 yards apart, and the troughs 5 to 20 feet deep; near Point Moss, where the thickness of the ice shelf is probably much less, the ridges are about 100 yards apart, and the troughs not more than 5 feet deep (Hattersley-Smith, 1956, p. 233). In Dronning Maud Land, where the ice shelf is about 190 metres (620 feet) thick, the ridges are said to be about 1 kilometre (1,100 yards) apart, and the troughs about 10 metres (30 feet) deep (Swithinbank, 1955, pp. 64, 73). In describing the undulations on the Ross Ice Shelf, Debenham (1948, p. 210) observed that "their direction and symmetry seem to indicate a factor operating with regularity from seaward", but Swithinbank (loc. cit.) states that "the origin of such depressions is quite unknown".

Under present conditions in northern Ellesmere Island undulations originating from any cause would be perpetuated by the drainage of melt-water, which does not occur in the Antarctic. The original siting of the ridges and troughs on the Ellesmere Ice Shelf could have been due to any one of the following possible causes: movement of the ice shelf, movement of the land glaciers, temperature changes, pressure of the pack ice, tidal action, or wind action.

At the present time no glaciers exert large scale lateral pressure on the Ellesmere Ice Shelf, and there is no sign of any *en masse* movement of the ice shelf away from the coast, except when ice islands break away along lines of fracture. It has been stated that antarctic ice shelves have a general surface elevation of between 37 and 45 metres (120 and 150 feet) above sea level, and it has been shown that they are subject to spreading under their own weight (Swithinbank, 1955, pp. 64, 72). It may be that this sort of movement would be negligible on the Ellesmere Ice Shelf, whose surface elevation probably nowhere exceeds 25 feet above sea level (Fig. 2). Measurements on the ice shelf in Markham Bay are inconclusive on this point, but they do show that between May 1953 and September 1954 any movement along a north-south line did not exceed 5 feet.

Pressure by a glacier has been stated to be the cause of folded bay ice in Marguerite Bay, Graham Land (Nichols, 1933, p. 130-3). It has been suggested that during the history of the Ellesmere Ice Shelf the glaciers along the *outer* part of the coast have never extended much beyond their present limits (Hattersley-Smith, 1955, p. 23-5). As Debenham (1954, p. 497) has pointed out, it is unwarranted to suppose that the rolls on the outer part of the ice shelf are due either to movement of the land glaciers or movement of the ice shelf. However, inside the fiords, as at the head of Milne Bay, rolls on the ice shelf have undoubtedly resulted from glaciers moving out into the fiord. The air photographs suggest that the rolls are mainly due to crevasses in the floating glacier tongues that merge with the ice shelf (see also Marshall, 1955, p. 112), rather than to buckling of the ice shelf under the pressure of

the glaciers. On the outer part of the coast between Alert Point and Cape Alfred Ernest the remnant of ice shelf is partly composed of a floating ice tongue, which has well developed surface rolls (Fig. 4). But glacier pressure cannot be regarded as the main cause of the rolls even in the fiords, because the whole series of rolls from the fiords to the outer edge of the shelf, which is 12 miles from the mainland north of Ward Hunt Island, show a remarkable uniformity (Fig. 1).

Rolls have been explained as due to temperature changes, in order to account for their parallelism to the shore. Wright and Priestley (1922, p. 344) gave this explanation for ridges and troughs parallel to the shore on the east side of McMurdo Sound, South Victoria Land: "a rise of temperature, acting over a very large area, causes expansion in the ice-sheet, especially when the latter is thick. This, in turn, sets up considerable pressure which is usually concentrated along shore lines, or against immovable objects such as islands and stranded bergs." Zubov (1955, p. 5) has suggested a similar explanation of the rolls on the Ellesmere Ice Shelf. "The temperature of the lower surface of ice, when it is afloat, is always close to the freezing point, while on the top surface it fluctuates, in the course of the year, over a range from zero to 40-50° below zero [centigrade]. If we take it that the ice shelf is at some times resting on the bottom so that its lower surface is immovable, then temperature fluctuations might cause either fissures or folds in the ice, and . . . they will be parallel to the shore line."

Measurements on the ice shelf in 1954 showed that seasonal variations in temperature occur only in the upper 40 feet of ice (Crary, *in* Hattersley-Smith *et al.*, 1955, p. 30). Permanently grounded ice, as the ice rises (Koenig *et al.*, 1952, p. 66), can be recognized by the lack of rolls and by the strand cracks that mark the junction with the ice shelf. The observations and soundings east and west of Ward Hunt Island (Crary, 1956) strongly suggest that the ice shelf in this region is floating throughout its extent, except possibly over limited areas near its edge, where it may intermittently be grounded. No fissures, as postulated by Zubov, were observed on the ice shelf, unless the troughs themselves are to be regarded as fissures that have been enlarged by melt-water. The floating nature of the ice shelf and the complete lack of rolls on the ice rises constitute the principal objections to Zubov's hypothesis.

Debenham (1954, p. 504) and Zubov (1955, p. 5) have suggested that the pressure of the pack ice may be responsible for producing the rolls in the coastal fringe of the ice shelf. But it is difficult to see how pressure of the pack could in any way influence roll formation at the present time, because, north of Ward Hunt Island for example, the pressure can only act on a thin edge of the 12-mile wide ice shelf. At its edge the ice shelf is believed to be not more than about 35 feet thick, whereas near the mainland it is as much as 150 feet thick, according to seismic soundings by A. P. Crary. Under these conditions pressure of the pack could hardly cause folding. It is possible, however, that the pressure of the pack may have influenced the original siting

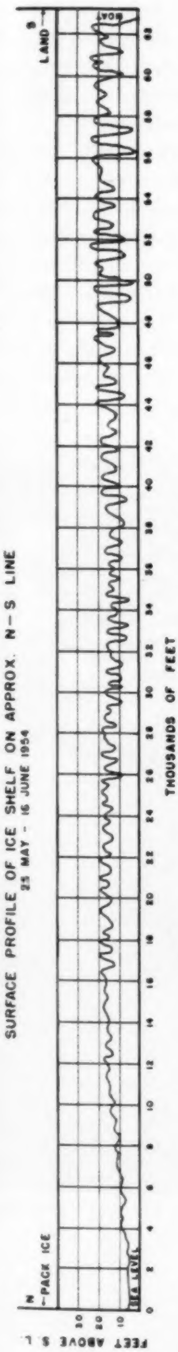


Fig. 2. Surface profile of ice shelf west of Ward Hunt Island.

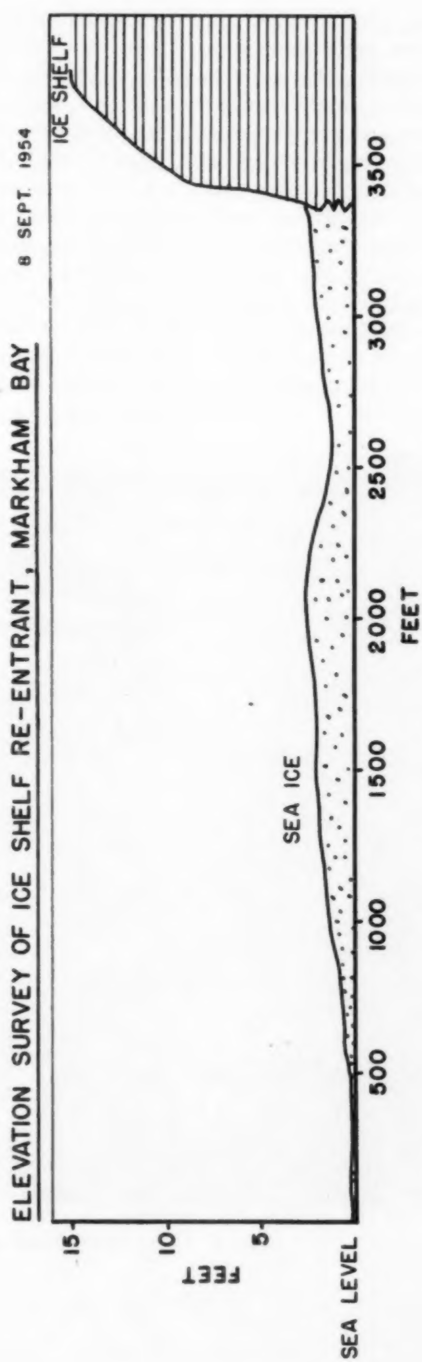


Fig. 3. Surface profile of ice shelf re-entrant off Markham Bay.

of the rolls at the bay ice stage of ice shelf formation, as exemplified by the ice that has formed in the Markham Bay re-entrant to a thickness of 20 feet since 1946 (Hattersley-Smith *et al.*, 1955, p. 23) (Fig. 3). A slight tendency toward a linear arrangement of the melt-water lakes between low pressure ridges was observed on the ice of the Markham Bay re-entrant, and could possibly represent an early stage in ridge and trough development, on the assumption that the lakes are subsequently deepened by melt-water flow. In Yelverton Bay more or less regularly spaced "hedges" of pressure ice, separated by a few hundred yards of smooth ice, probably about 15 feet thick, were observed in May 1954, and suggested a way in which a system of rolls might be started. Continual snow accumulation on the surface during the upward growth of the ice shelf might smooth out the rough ridges of the pressure ice to give a series of gentle undulations. An incipient ridge and trough pattern that could possibly have been formed in this way can be seen in an air photograph of sea ice off Phillips Bay (Fig. 4) (but see p. 42).

Photo: R.C.A

Fig. 4. Cape Alfred Ernest and Phillips Bay.

Tidal action has been invoked to explain the origin of the rolls on the Ross Ice Shelf (Siple, 1945, p. 57; Poulter, 1947, pp. 377-83; Debenham, 1948, pp. 210-11). Debenham envisages a series of parallel cracks being formed by tidal action near the seaward edge of the ice shelf. Sea-water fills the cracks, and, since the temperature of the ice shelf is low, freezes up to sea level. The sea ice remains as a permanent line of weakness and tends to keep open the crack, which in its upper part becomes filled with drift snow. In Dronning Maud Land depressions along the seaward margins of the ice shelves are also thought to represent lines of structural weakness (Swithinbank, 1955, p. 73). The bottoms appeared to be "falling out" of these depressions, and Swithinbank concluded that this vertical movement is "normal and continuous", for otherwise no depression could survive filling-in by drift snow. Evidently the spreading of an antarctic ice shelf under its own weight plays a part in the formation of the depressions, but it is doubtful whether the Ellesmere Ice Shelf has any significant movement of this kind (p. 35).

In relatively thin ice tidal action can cause a system of parallel transverse cracks to develop; an air photograph of Hare Fiord off Nansen Sound shows such cracks in bay ice probably not more than 6 to 8 feet thick. If further cracks were to develop in the ice of this fiord, differential melting, due to penetration of sea-water, and melt-water erosion might conceivably combine to produce a system of ridges and troughs, as on the Ellesmere Ice Shelf. That cracks may occur in the lower part of the ice shelf is suggested by the influx of salt-water into the bottom of the 80-foot bore-hole at the 1954 main camp, where seismic soundings by A. P. Crary showed the ice shelf to be about 120 feet thick. But a crevasse was observed in only one place on the surface of the ice shelf.

The rolls could perhaps also be regarded as expressing the plastic response of the ice shelf to the tide, which acts gradually and progressively toward the land, so that there is a definite time interval between its effect near the edge of the shelf and its effect, say, along the latitude of Ward Hunt Island. The tidal effect could perhaps be measured by simultaneous levelling at various points along the north-south line. In the early days of the ice shelf, when it was relatively thin, tidal stresses might have been taken up by rafting and buckling of the ice. Later, as the ice shelf became thicker, perhaps with the worsening of the climate and increased accumulation at the surface, the tidal stresses may have been taken up by actual plastic deformation. Debenham (1954, p. 499) considers that deformation, caused by tidal action, is responsible for the rolls on the ice shelf in the fiords, on the assumption that the ice shelf is grounded at the sides of the fiords.

To each of the various possible explanations of the rolls, involving fracture or deformation of the ice shelf, that have been mentioned above, certain objections have been raised. Furthermore, none of these explanations can account for the astonishing regularity of direction and spacing of the rolls over the whole extent of the ice shelf.

It remains to examine the possible connection between wind action and rolls on the Ellesmere Ice Shelf. At the present time, wind does not have any important effect on the form of the ridges and troughs, because they are features of the ice and not of the superficial snow, which alone could be readily affected by the wind and which in fact tends to be slightly deeper in the troughs than on the ridges. Moreover the snow has provided no net increment at the surface during at least the last 45 years, as is shown by the finding of relics of a Peary expedition on the surface of the shelf (Hattersley-Smith *et al.*, 1955, p. 23). A minor effect of the prevailing westerly winds has been the promotion of drainage by the driving of melt-water eastward in the trough lakes in summer. But any connection between wind and original development of the troughs must be sought not under present day conditions, but under conditions prevailing when the shelf was being built up and all the winter snow did not melt in summer.

If the rolls were initiated by wind action, their east-west trend indicates that they began as elongated snow dunes parallel to the direction of the dominant westerly winds. Their tendency to swing southward into the fiords could be due to deflection of the winds, and their tendency to become disorganized at the heads of the fiords could be due to strong winds of variable directions induced by the local topography (Fig. 1), including katabatic winds from the ice cap parallel to the axes of the valleys. The fact that parallel ridges and troughs occur on the ice of a lake in a valley, 15 miles south of the head of Ayles Bay (Fig. 1) (Montgomery, 1952), strongly suggests that the ridges and troughs on the ice shelf are in no way associated with forces acting from the sea. A similar pattern of ridges and troughs occurs on another lake a few miles south of Cape MacMillan to the west of Phillips Bay (Fig. 5).

The following observations may support the hypothesis of wind origin. On the ice island T3 deep borings gave evidence of a migration of the surface rolls during the growth of the ice shelf (Crary *et al.*, 1955, No. 7, p. 2). If the rolls originated as a system of snow dunes, it would not be surprising to find that they migrated like sand dunes.

According to Bagnold (1941, pp. 178-9), there is a tendency for sand to be deposited in longitudinal strips under the influence of a strong wind from the same direction, blowing over a surface of absolute uniformity. Bagnold suggests that a large scale rotary movement in the air tends to scour the sand from the area between the strips, depositing it on either side. When the wind regime includes a strong wind from one direction with gentler winds from transverse directions, the sand is driven laterally into the sand-covered strips, and the conditions are right for the formation of longitudinal or *seif* dunes (Bagnold, 1941, p. 195). *Seif* dunes may grow to as much as 300 feet in height and may be as much as 60 miles long. The distance between the dunes remains approximately the same over a large area, and "is probably a statistical effect dependent on the sand supply". (Bagnold, 1941, pp. 229, 232). The ratio of this distance to the height of the dune varies widely from one region to another.

Fig. 5.
Glacier-dammed
lake south of
Cape MacMillan.

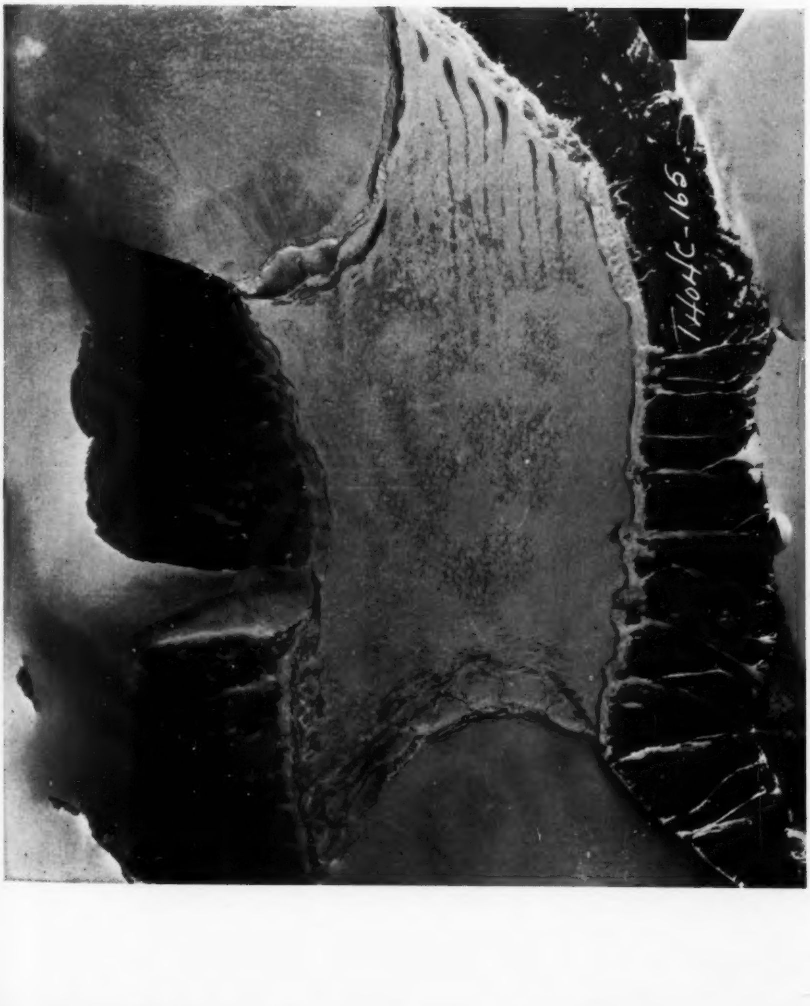


Photo: R.C.A.F.

It is believed that some such processes may have been responsible for the development of the rolls on the Ellesmere Ice Shelf, where the strong winds and the bulk of the precipitation come from a general westerly direction, but where gentler winds blow from other quarters, chiefly the northeast. It could be expected that the form of the individual snow-flakes is also important. The more rounded and compact the snow-flakes—or the more they resemble sand grains—the more favourable are the conditions for *seif* dune formation.

Ice barchans occur on the mainland south of Ward Hunt Island (Fig. 6); their horns point eastward. Similar features occur near Hansen Point. Dune bedding was observed in the steep trough walls on the ice shelf in Disraeli Bay (Marshall, personal communication, 1954). Undoubted wind-drift formations occur near the Marvin Islands (Hattersley-Smith *et al.*, 1955, p. 14), and on the mainland south of Cape Albert Edward. These features are probably in equilibrium with the wind strength and the supply of snow.

Of special significance are the rolls, attributed to snow dunes, that occur on the smooth bay ice of the Markham Bay re-entrant formed since 1946 (cf. p. 38). They run parallel to the rolls of the adjacent ice shelf, but appear to have about half the "wave length" of the latter (Fig. 7). They were not noticed during the elevation survey (Fig. 3), which was made after the snow had melted. Similar rolls can also be seen on the bay ice in air photographs of Phillips Bay (Fig. 4), and Baird (1955, p. 104) has drawn attention to similar features on fiord ice in northeast Baffin Island. The presence of these features constitutes a strong argument in favour of a wind origin of the rolls on the ice shelf. The longer wave length on the ice shelf could be due to a difference in wind strength and snow supply during formation. The absence of rolls on the ice rises is attributed to the slope of the ice rises, which would cause the rolls to be obliterated by the surface drainage of melt-water. The absence of rolls on the hummocky ice of Clements Markham Inlet and

Fig. 6. Ice barchans on mainland, south of Ward Hunt Island. July 30, 1954.

on the broken bay ice of the outer part of the Markham Bay re-entrant suggests that the wind will not form rolls unless the ice surface is absolutely level and smooth. Such a surface also implies less snow cover, and hence a greater potential thickness of ice.

Of various possible agencies that may have caused the rolls on the Ellesmere Ice Shelf, wind action appears the most likely. It is suggested that the original development of the rolls was analogous to the formation of *seif* dunes in the desert. Since the wind is not forming rolls on the ice shelf today, they should be regarded as "fossil" snow dunes that have been perpetuated by the annual drainage of melt-water.

Field work by R. L. Christie, A. P. Crary, and E. W. Marshall provided much of the material on which this paper has been based.

Photo: R.C.A.F.

Fig. 7. Re-entrant of ice shelf off Markham Bay. Cape Nares in centre.

References

Bagnold, R. A. 1941. The physics of blown sand and desert dunes. London: xx+265 pp.
Baird, P. D. 1955. Glaciological research in the Canadian Arctic. Arctic 8: 96-108.
Crary, A. P. 1954. Seismic studies on Fletcher's ice island, T-3. Trans. Am. Geophys Un. 35: 293-300.
——— 1956. Geophysical studies along northern Ellesmere Island. Arctic 9: 155-65.
Crary, A. P., R. D. Cotell, T. F. Sexton, R. R. Shorey, and N. Goldstein. 1955. Scientific reports of GRD at Fletcher's ice island, T-3. Geophysics Research Directorate, Air Force Cambridge Research Center. Progress Reports, Nos. 7 & 8 (unpublished).
Debenham, F. 1948. The problem of the great Ross Barrier. Geog. J. 112: 196-218.
——— 1954. The ice islands of the Arctic: a hypothesis. Geog. Rev. 44: 495-507.
Hattersley-Smith, G. F. 1956. Glaciological reconnaissance in northern Ellesmere Island. Pub. No. 39 de l'Assoc. Int. d'Hydrol. (Assemblée Générale de Rome, tome iv), pp. 229-35.
Hattersley-Smith, G. F., A. P. Crary, and R. L. Christie. 1955. Northern Ellesmere Island, 1953 and 1954. Arctic 8: 3-36, map.
Koenig, L. S., K. R. Greenaway, Moira Dunbar, and G. F. Hattersley-Smith. 1952. Arctic ice islands. Arctic 5: 67-103.
Marshall, E. W. 1955. Structural and stratigraphic studies of the northern Ellesmere ice shelf. Arctic 8: 109-14.
Montgomery, M. R. 1952. Further notes on ice islands in the Canadian Arctic. Arctic 5: 183-7.
Nichols, R. L. 1953. Geomorphology of Marguerite Bay, Palmer Peninsula, Antarctica. Office of Naval Research, Washington, D.C., 151 pp.
Poulter, T. C. 1947. Seismic measurements on the Ross Shelf Ice. Part II. Trans. Am. Geophys. Un. 28: 367-84.
Robin, G. de Q. 1954. Dronning Maud Land, Antarctica, *in* Depth of polar ice caps. Geog. J. 120, pt. 2: 197-201.
[Roscoe, J. H.]. 1953. Regional photo interpretation series: Antarctica. Air Force Manual 200-30. Washington, D.C., 171 pp. and 2 maps.
Siple, P. A. 1945. Geographical exploration from Little America III, the west base of the United States Antarctic Service Expedition 1939-41. Proc. Am. Phil. Soc. 89: 23-60.
Swithinbank, C. W. M. 1955. Ice shelves. Geog. J. 121, pt. 1: 64-76 and map.

AN ARCTIC ALASKAN KELP BED*

John L. Mohr[1], Norman J. Wilimovsky[2], and E. Yale Dawson[1]

THE purpose of this paper is to report an unusual occurrence of a kelp bed in arctic Alaskan waters, to describe its composition and its associated fauna, including a fish new to the Arctic, and to point out the significance of the lack of extensive kelp beds in the Alaskan Arctic for the development of the fauna. The studies on which this paper is based were aided by a contract between the Office of Naval Research, Department of the Navy and the Arctic Institute of North America, Inc., and by a contract between the Office of Naval Research and Stanford University. The field work was conducted from the Arctic Research Laboratory of the Office of Naval Research, Point Barrow, Alaska. Reproduction in whole or in part is permitted for any purpose of the United States Government.

We are indebted to Dr. Ira L. Wiggins and to Prof. and Mrs. G. E. MacGinitie for stimulating discussions of the problems raised and to all persons participating in the field work. The aid given by Mr. Oliver Newton of the University of Southern California herbarium is gratefully acknowledged.

Probably no other feature of the marine biota of the Point Barrow area of northern Alaska is more striking than the absence of a macroscopic benthic algal component. Although occasionally stranded pieces of laminarioids are found, careful search of the shores after storms has usually yielded no conspicuous algae, though sessile animals (sponges, bryozoans, hydrocorals, tunicates) have been present in abundance and even mats of dislodged tundra plants have occurred. Farlow's (1885) paper in the Report of the International Polar Expedition to Point Barrow lists only *Phyllophora interrupta* (Grev.) J. Agardh, *Odonthalia dentata* Lyngbye and an undeterminable rhodophycean (possibly *Rhodymenia pertusa* (Bail. and Harv.) J. Agardh) and fragments of an *Ulva.* Collins (1927) reports no laminarioids in the collections of the Canadian Arctic Expedition 1913-18 between a station (at 69°30'N 163°27'W) below Point Lay west of Point Barrow and Spy Island (70°33'N 149°40'W) to the east. His data permit the interpretation that no extensive stands of laminarioids were encountered between western Alaska and Dolphin and Union Strait, N.W.T. (116°30'W).

*Allan Hancock Foundation Publication No. 191.
[1]University of Southern California.
[2]Stanford University, present address: U.S. Fish and Wildlife Service, Juneau, Alaska.

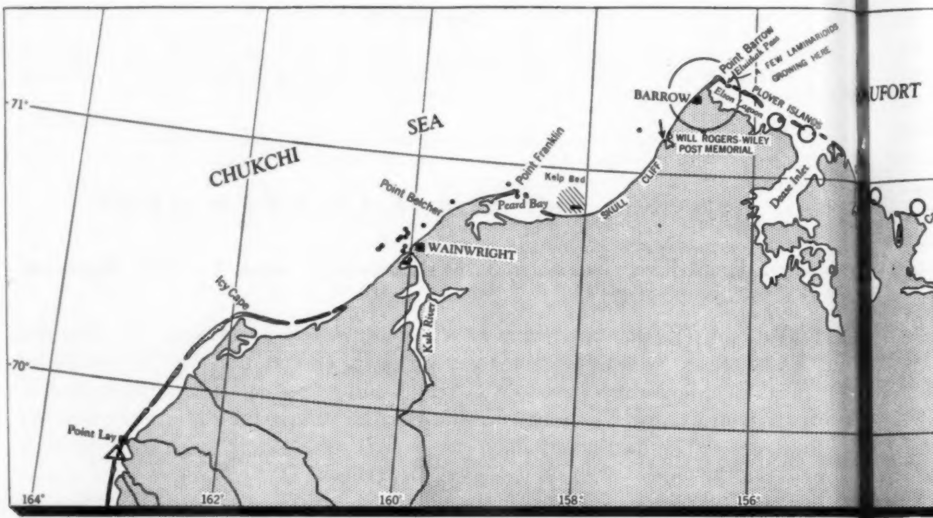
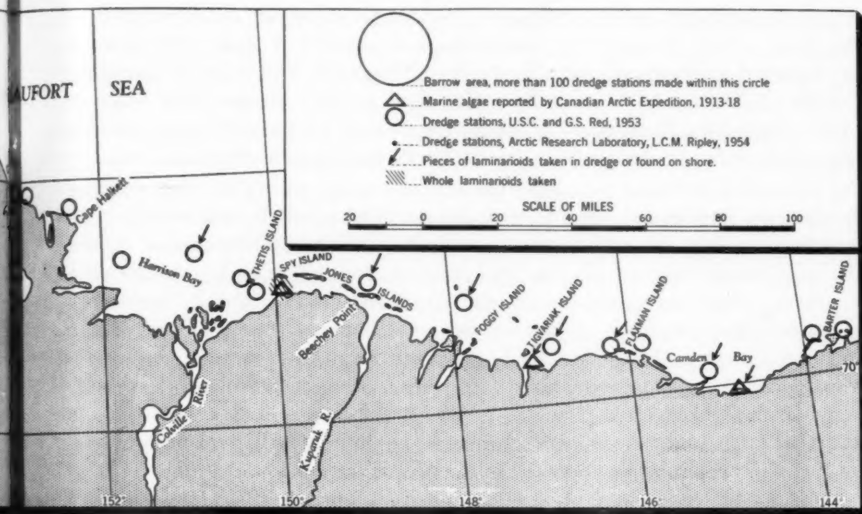


Fig. 1. Biological collecting stations along arc ka. Mo made in the waters off Barrow, f. E. G.

Consequently it is noteworthy that a kelp bed was encountered on a cruise made by the LCM *William E. Ripley*, research vessel of the Arctic Research Laboratory, Point Barrow. On August 10, 1954 a four-foot biological dredge was towed for about twenty minutes (from 2035 to 2055) in water about 39 feet deep approximately 50 miles southwest of Point Barrow at 70°51′30″N 158°08′30″W (Cruise II, Station 20; Wilimovsky, 1954). When raised to the deck, the dredge was overflowing with seaweeds. Dr. G. Dallas Hanna, geologist of the cruise, characterized the bottom as "rocky with a minor amount of sand" (Fig. 2).

The laminarioid *Phyllaria dermatodea* (De La Pylaie) Le Jolis was the dominant alga. Two other phaeophyceans, *Laminaria saccharina* (L.) Lamouroux and *Desmarestia viridis* (O. F. Müller) Lamouroux, were abundant and seven rhodophyceans were represented, namely *Turnerella pennyi* (Harvey) Schmitz, *Phyllophora interrupta* (Grev.) J. Agardh, *Antithamnion americanum* (Harvey) Farlow, *Phycodrys sinuosa* (Good & Wood) Kütz, *Polysiphonia arctica* J. Agardh, *Odonthalia dentata* (L.) Lyngbye, and (probably) *Rhodomela lycopodioides* f. *flagellaris* Kjellman. Materials of these species have been deposited in several herbaria: U.S. National Herbarium, Washington, D.C.; Allan Hancock Foundation, University of Southern California, Los Angeles; Dudley Herbarium, Stanford University; University of California, Berkeley; University of Michigan, Ann Arbor; University of



ka. More than 125 additional stations have been
f. E. G. MacGinitie or the writers.

British Columbia, Vancouver; University of Illinois, Urbana; University of Minnesota, Minneapolis; Arctic Research Laboratory; British Museum (Natural History).

Taken among the algae were relatively few invertebrates (all polychaetous annelids and arthropods) and six species of fishes. The polychaetes were represented by numerous serpulids (*Spirorbis* sp.) attached to brown algae and by a scaleworm (Polynoidae). The arthropods, all crustaceans, included numerous *Caprella* sp., six hermit crabs (Paguridae), a true crab (*Hyas coarctatus aleuticus*) and four genera of shrimps: many *Sclerocrangon*, one individual with a parasitic isopod, *Argis*, *Eualus*, and a few *Spirontocharis*.

The fishes comprise the polar cod, *Boreogadus saida* (9 individuals), a single juvenile of *Gymnelis viridis*, and four species of cottids. Of these the cod may have been feeding on the benthos, while the remaining species are characteristic bottom inhabitants. The cottids include 16 examples of *Gymnocanthus tricuspis*, a like number of *Myoxocephalus scorpius*, and 13 *Artediellus scaber beringianus*. The fourth species of cottid, *Enophrys diceraus*, represented by two small examples, deserves some remarks as it is heretofore unrecorded from arctic waters. *Enophrys diceraus* (Pallas), which is known from the Okhotsk and Bering Seas to Southeast Alaska, has been recorded only once north of Cape Olyutorsky, Kamchatka. Andriyashev (1952) records this species from Providence Bay on the southern Chukchi Peninsula, Bering Sea,

where, he intimates, it is a straggler. Our find is some 600 miles northeast of this point. Meristic and other morphological features of these specimens will be reported upon elsewhere (N. J. W.). Popov's (1933) observation that *Enophrys diceraus* in Avatcha Bay, Kamchatka, "was always taken from the rocks covered by Serpulidae" is interesting in view of the numerous *Spirorbis* (Serpulidae) found attached to the *Phyllaria* dominant in the kelp bed.

Several fishes were examined for stomach contents. The food was predominantly crustacean. The polar cod contained small to tiny benthic gammaridean amphipods and numerous copepods. As the cottids occupy essentially one habitat, for our purposes the stomach contents may be considered as a whole. They contained mainly gammaridean and caprellidean amphipods, an unidentified juvenile crab, a small shrimp (*Sclerocrangon*), and polychaete and molluscan (probably pteropod, *Limacina*), remains. A small amount of plant material could be recognized. It is interesting that the general proportions of the crustaceans, particularly of amphipods, to other forms in the stomachs of these fishes are consistent with the findings of Pirozhnikov (1955) for fishes of the estuarine areas of the Laptev Sea.

Of the animals taken with the algae in this dredge-haul, only the caprellids and *Spirorbis* appear to be closely tied to the algal association although the taking of four species of cottids suggests the importance of the bed as a feeding

Fig. 2. Four-foot dredge with algae on deck of LMC *William E. Ripley*, August 10, 1954. The principal species about the mouth of the dredge is *Phyllaria dermatodea.*

area. Caprellids elsewhere in this region occur on sponges, bryozoans, tunicates, or other organisms which provide elevated positions in the habitat. Wesenberg-Lund (1951) has remarked that *Spirorbis spirillum* (which may be conspecific with our examples) is confined to brown algal substrates. Pettibone (1954) claims to have found this species in a variety of situations, none algal, about Point Barrow. The faunal components suggest that the kelp bed supplies a combination of habitats for forms ordinarily found on a number of different substrates of the North Alaskan shelf, but they do not in themselves constitute a characteristic kelp bed facies.

Although the natural sequence of occurrence of the plants may have been somewhat disturbed in the course of dredging, the coarser brown algae were observed at the top of the dredge (that is, they were presumably taken during the last portion of the haul) and the smaller red algae were in the deeper part of the dredge (thus taken in the early part of the haul). Because the dredge-haul was run from deeper water farther offshore in a shoreward direction, it is inferred that the algae were vertically stratified in their natural habitat. This stratification, involving some of the same species, has been noted for North East Greenland by Rosenvinge (1910) and Thorson (1933). That these algae probably occur in separate beds, at least in some nearby stands, is evidenced by the finding of large quantities of one species, *Phycodrys sinuosa*, strewn on the beach (71°18′N 157°12′W) in the same general area after more than a week of heavy seas. Because this stranding was observed August 27, 1954, less than three weeks after the collection reported was made, the absence of laminarioids from the windrows cannot be accounted for by seasonal variation. The fishes taken also suggest that two types of bottom areas were sampled in the dredging. Collection records of fish (N. J. W.) indicate that whereas *Gymnocanthus* and *Myoxocephalus* are frequently taken together, *Artediellus* does not ordinarily occur with *Gymnocanthus*.

The validity of our conclusions as to the floral poverty of much of northern Alaska may be open to question. The accuracy of our observations is limited by the small number of samples and by the fact that no phycologist took part in our field work, with the further consequence that no special gear for taking algae was employed. Some beds were almost certainly missed in the sampling patterns. Particularly, inconspicuous forms were probably taken, but overlooked by collectors specializing in other groups. Recognizing these limitations, we still believe that the generalization is justified that there occur only few and small algal beds, limited in species and in numbers of individuals. These conclusions are based on the following data: The occurrence of laminarioids in only three of the more than 20 stations between Point Lay, Alaska, and Dolphin and Union Strait, N.W.T., occupied by the Canadian Arctic Expedition 1913-18 (Collins, 1927). The representation of laminarioids at only six (and these by fragments only) of 18 stations occupied by the U.S. Coast & Geodetic Survey LCM *Red* in 1953 (N. J. Wilimovsky participating) between Barter Island and Point Barrow, Alaska (Wilimovsky, 1953), and

the lack of any laminarioids at 17 of 18 stations occupied by the Arctic Research Laboratory LCM *William E. Ripley* in 1954 between Point Barrow and Wainwright, Alaska (J. L. M., N. J. W. participating [Wilimovsky, 1954]). A further lack of any examples of brown algae from many stations in the vicinity of Point Barrow during the summers of 1951 to 1954 and from the strand-lines after storms appear to us to substantiate MacGinitie's (1955) observation of "the total absence of macroscopic algae (except for about two species in Elson Lagoon)" from the Barrow area. In their general reviews, neither Shchapova (1948) nor Taylor (1954) mentions the existence of kelp beds along the arctic coast.

Equally important in considering the accuracy of the opinion that northern Alaska is poor in marine algae, both in comparison with lower latitudes on the Pacific Coast and with corresponding latitudes of Greenland, are available data on the character of the bottom sampled (Buffington *et al.*, 1950; Carsola, 1952). These indicate that the general substrate from western arctic Alaska to beyond the Mackenzie Delta in the east is composed of sediments without large regions of rocks or boulders. Dall (1875) points out for the Bering Sea that "the distribution of the algae seems to be largely dependent on the character of the rocks" and that the absence of algal stands from large portions of the borders of that sea is directly connected with the presence of sediments. Although virtually ripe fruiting areas were observed on fronds of the dominant *Phyllaria dermatodea*, both in the field and during laboratory examination (E. Y. D.), we have no data on reproduction and continuity of any of the algal beds. It seems likely that at least some of the kelp beds have more than a single season's duration. Examination of known inshore current patterns (U.S.C. & G.S., 1947) does not suggest that annual "seeding" alone would account for such a well established kelp bed as that reported here. The establishment and development of sporophytes is limited by the fact that their probable major period of production (late summer and fall) occurs at the time of greatest turbulence and sedimentation in the inshore waters, with the probability of their effective burial or the prevention of their attachment to suitable rocky substrates in the few areas in which these are present. MacGinitie's (1955) observations on the churning of bottom sediments and attendant silting effects by sea ice in winter give an especially clear picture of a force precluding the general establishment of kelp beds.

The data are too few to warrant more than provisional generalizations about the effects on the biota resulting from the lack of extensive beds of macroscopic algae along the Alaskan arctic coast. Certainly the presence of such plants in other northern areas provides there a broader energy base (photosynthetic) and appears to result in a much richer fauna. This may be manifested in the benthic biomass, in the presence of abundant reproductive stages (cf. Thorson, 1935, on the egg cases of gastropods in West Greenland), or even the existence of a *Fucus* epifauna in the intertidal between boulders at Thule (Vibe, 1950).

References

Andriyashev, A. P. 1952. Tikhookeanskiye kraby i ryby na severe. Priroda Vol. 1952, No. 5: 116.

Buffington, E. C., A. J. Carsola, and R. S. Dietz. 1950. Oceanographic cruise to the Bering and Chukchi Seas. Part I: Sea floor studies. U.S. Navy Electronics Laboratory, San Diego, California, NE 120202, Rept. 204, 26 pp.

Carsola, A. J. 1952. Marine geology of the Arctic Ocean and adjacent seas off Alaska and northwestern Canada. Doctoral dissertation, Univ. of California at Los Angeles.

Collins, F. S. 1927. Marine algae. Rept. Can. Arc. Exp. 1913-18, Vol. 4, Pt. B: 3-16.

Dall, W. H. 1875. Arctic marine vegetation. Nature 12: 166.

Dawson, E. Y. 1947. A guide to the literature and distributions of the marine algae of the Pacific coast of North America. South. Calif. Acad. Sci., Mem. 3: 1-134.

Farlow, W. G. 1885. *In* Asa Gray, Plants, Rept. of the Int. Polar Exp. to Point Barrow, Alaska. Washington, D.C.: G. P. O., pp. 191-2.

Hanna, G. D. 1954. Submarine geological investigations off Point Barrow, Alaska, 1954. Res. Rept. to Arc. Inst. of N. Am., Contract No. 1138(01), pp. 1-10.

Howe, M. A. 1927. Report on a collection of marine algae made in Hudson Bay. Rept. Can. Arc. Exp. 1913-18, Vol. 4, Pt. B: 18-30.

Kjellman, F. R. 1883. The algae of the Arctic Sea. A survey of the species, together with an exposition of the general characters and development of the flora. K. Svenska Vetenskaps-Akademiens Handlingar 20: 1-350.

MacGinitie, E. G. 1955. Distribution and ecology of the marine invertebrates of Point Barrow, Alaska. Smithson. Misc. Coll. Vol. 128, No. 9, iv + 201 pp.

Pettibone, M. H. 1954. Marine polychaete worms from Point Barrow, Alaska, with additional records from the North Atlantic and North Pacific. U.S. Nat. Mus., Proc. 103: 203-356.

Pirozhnikov, P. L. 1955. Pitanie i pishchevye otnosheniya ryb v estuarnykh rayonakh morya laptevykh. Voprosy Ikhtiologii 3: 140-185.

Popov, A. M. 1933. Fishes of Avatcha Bay on the southern coast.of Kamtchatka. Copeia Vol. 1933, No. 2: 59-67.

Rosenvinge, L. K. 1917. On the marine algae from north-east Greenland (N. of 76° N. lat.) collected by the Danmark-Expedition. Medd. om Grønl. Vol. 43, No. 4: 91-134.

Saunders, De A. 1901. Papers from the Harriman Alaska Expedition. XXV. The algae. Wash. Acad. Sci., Proc. 3: 391-486.

Shchapova, T. F. 1948. Geograficheskoe rasprostranenie predstaviteley poryadka Laminariales v severnoy chasti tikhogo okeana. Akad. Nauk, SSSR., Instituta Okeanologii, Trudy 2: 89-138.

Smith, G. M. 1944. Marine algae of the Monterey peninsula, California. Stanford University Press, vii + 622 pp.

Taylor, W. R. 1937. Marine algae of the northeastern coast of North America. Ann Arbor: University of Michigan Press. Univ. Mich. Sci. Ser. Vol. 13, vii + 427 pp.

———— 1954. The cryptogamic flora of the Arctic. II. Algae: non-planktonic. Bot. Rev. 20: 363-99.

Thorson, G. 1933. Investigations on shallow water animal communities in the Franz Joseph Fjord (East Greenland) and adjacent waters. Medd. om Grønl. Vol. 100, No. 2: 5-70.

———— 1934. Contributions to the animal ecology of the Scoresby Sound fjord complex (East Greenland). Medd. om Grønl. Vol. 100, No. 3: 5-68.

———— 1935. Studies on the egg-capsules and development of arctic marine prosobranchs. Medd. om Grønl. Vol. 100, No. 5: 5-71.

U.S. Coast & Geodetic Survey. 1947. United States Coast Pilot, Alaska. Part II. Yakutat Bay to Arctic Ocean. 5th Edition. Washington: G. P. O., xi + 659 pp.

Vibe, C. 1950. The marine mammals and the marine fauna in the Thule district (Northwest Greenland) with observations on the ice conditions in 1939-41. Medd. om Grønl. Vol. 150, No. 6: 3-115.

Wesenberg-Lund, E. 1950. The Polychaeta of West Greenland with special reference to the fauna of Nordre Strømfjord, Kvane-, and Bredefjord. Medd. om Grønl. Vol. 151, No. 2: 5-171.

Wilimovsky, N. J. 1953. Cruise of the U.S. Coast and Geodetic Survey LCM "Red". I. Introduction, itinerary and station list. II. Temperature and salinity records. Stanford Univ., Nat. Hist. Mus., Contract N 6onr-25136 NR 307 204, Technical Report III, 3 pp.

——— 1954. Station data–1954 Cruises, LCM "William Ripley". Ibid., Technical Report VI, 5 pp.

REVIEWS

GRØNLANDS FLORA [THE FLORA OF GREENLAND]

By Tyge W. Böcher, Kjeld Holman, and Knud Jakobson, illustrated by Ingeborg Frederiksen. *Copenhagen: P. Haase & Søns Forlag, 1957. 7½ x 4¾ inches; 314 pages; 54 figures, 2 colour plates. 28.00 kroner ($4.00).*

Few visitors to Greenland, coming from countries more favoured by nature, have failed to express surprise and delight over the beauty and relative abundance of wild flowers in that island. Not a few have been much disappointed that no guide or manual was available to help them in naming the flowers that greeted them on landing there. This lack is the more surprising as, botanically speaking, the flora of Greenland has been studied longer and more intensely than that of any other arctic land. The need for a guide to the flora of Greenland was recognized by the late Morten P. Porsild, who in 1901 prepared a "Flora Excursoria Groenlandica", intended mainly for his own use during his second visit to Greenland, when plans matured that later led to the establishment of a permanent scientific research station on Disko Island. At least four later "editions" of Porsild's flora are known to the reviewer, some even profusely illustrated by pen drawings. Of several there were handwritten copies that were freely lent to visitors to the Disko Station. However, despite much encouragement from friends and colleagues Porsild apparently never seriously considered publication of his guide to the flora of Greenland.

The urgent need for such a manual has at last been met and henceforth visitors to that island will have in "Grønlands Flora" a modern and convenient pocket guide to the flowering plants and ferns, complete with simple keys and descriptions that will satisfy the amateur as well as the professional collector. The book is attractively printed and profusely illustrated with excellent line drawings and two colour plates. It is also intended for use in the schools in Greenland and for this reason the synoptical part is preceded by a short introduction to the morphology of Greenland plants as well as by notes on their ecology and distribution. Present and future Greenland botanists will probably wish that space had permitted the inclusion of somewhat more detailed notes on the local distribution of the less common species. For the benefit of users not familiar with Danish, English equivalents are given for the abbreviations commonly used, besides an explanation in English and Greenlandic of the rather ingenious system of symbols by which plant distribution has been handled. These symbols together with the map at the end of the book on which the floristic provinces of Greenland are shown should prove quite adequate to all but local botanists. Those not familiar with Danish plant names would wish that Latin names had been inserted along with the Danish names in the main keys to families and genera on pages 34-5, 55-60, and 218-21. Danish plant names, accompanied by Latin binomials and trinomials are given throughout the text. Since many Greenland plants are North American and hence have no common Danish names, the authors of "Grønlands Flora" have been faced with the need for "inventing" plant names where none existed. To the reviewer the need for such "new" names sometimes seems questionable, particularly in the case of critical species that at best will remain fleeting acquaintances of Greenland schoolboys. However, many of the

"new" names are descriptive and well chosen; a few are redundant because common Danish names were available; and for the North American and East Asiatic subarctic *Anemone richardsonii*, which is in Greenland known only from a few stations in the central part of the west coast, the retention of Richardson's name would have seemed preferable to the new and misleading Danish "Sne [snow] anemone".

These, however, are all minor criticisms and the authors of "Grønlands Flora" are to be congratulated on having produced a most attractive and useful guide to the flora of Greenland.

A. E. Porsild

AN HISTORICAL EVALUATION OF THE COOK-PEARY CONTROVERSY

By Russell W. Gibbons. *1956. 10½ x 8 inches; 129 pp.; mimeographed.* Available through: *V. C. B. Co., P.O. Box 145, Hamburg, N.Y.; $1.00 postpaid.*

"The discovery of the North Pole has been delayed too long." So wrote R. M. Ballantyne in 1881, in the introduction to a novel in which he proceeded to rectify the situation by sending out an expedition equipped in his own fertile imagination. In view of the furore and generation of hot air and bad blood that resulted when the matter in fact reached its climax it is perhaps a pity that Mr. Ballantyne's discovery was not recognized. The question of whether Cook or Peary, or neither, or both, actually reached this theoretical point on the moving pack ice has always seemed to me of minor importance, and the vulgar brawl that followed their respective announcements one of the most dismal and undignified episodes in the history of exploration. Nevertheless a great number of people felt strongly on the subject, and apparently still do, as the controversy, though dormant, is by no means dead. And that is as it should be, because although the attainment of the pole in itself may be unimportant, an unfair judgement is something else, and there is little doubt that, whether he reached the pole or not, Cook was unfairly judged.

The latest blow to be struck in defence of Cook is by a young man who started off to write an undergraduate paper in the orthodox belief that Peary was a hero and Cook a liar, and became so impressed with the evidence to the contrary that he changed horses in midstream and wrote an impassioned plea for Cook. In doing so, however, he went to the opposite extreme, so that Peary emerges from his monograph as a fire-breathing monster whose horns are almost visible through his parka hood, while Cook wears the halo of the true martyr. The paper, revised and mimeographed, has now been distributed to "selected universities, libraries and geographic and historical societies".

I have no quarrel with Mr. Gibbons' basic theme: there is a good case for Cook, and there is little doubt he got a dirty deal. Peary had all the influential backing and big guns on his side and his supporters did not hesitate to use them. But all this has been said before, and it is questionable whether it is of any service to Cook's cause to repeat it unless there is new evidence to present or new and startling conclusions to be drawn from the old. Mr. Gibbons has no valid new evidence, and although some of his conclusions are startling they are not based on sound premises. The sad result is that his well-meaning and painstaking work is likely to do more harm than good to the cause that he so wholeheartedly and sincerely supports.

Mr. Gibbons loses our support in the introduction, before he even starts, by claiming that he will offer "incontrovertible proof" that Peary did not reach the pole. There are only two ways of proving incontrovertibly that anyone went anywhere—the evidence of a number of impartial witnesses, or evidence left at the place in question. To prove that someone did not go somewhere is even more difficult. At the North Pole there were no impartial witnesses and only moving ice on which to leave a record; there is not, therefore, and never can be,

incontrovertible proof that either explorer did or did not get there. All there can be is an analysis of the accounts of how they got there, so as to estimate their probable accuracy. The details of travel distances and observations for position have been thoroughly thrashed over already (but with widely differing interpretations) and only the appearance of new contemporary documents can greatly add to this line of investigation. There is another factor concerned, however: the ice conditions over which the two explorers claimed to have travelled. In this respect the state of our knowledge is growing rapidly, and in time may well produce important new evidence.

An attempt to introduce such evidence is made by Mr. Gibbons in a discussion of ice islands, which is unfortunately full of inaccuracies and misconceptions. He quotes this reviewer's contention (*Arctic*, Vol. 5, No. 2, p. 89) that Cook describes passing over what may have been an ice island on his polar journey. He goes overboard here as elsewhere, however, turning what is at best a good possibility into a certainty. "There can be no doubt that it was one of these fabulous floating fresh-water ice islands which Dr. Cook saw and wrote about forty years ago." That is obvious nonsense; there is room for all kinds of doubt. And even if we accept the ice island without question it still does not prove that Cook found it between 87° and 88°N as he states. (The fact that the position given is on what is now known to be the course of the ice islands' drift is however a good point, which may one day be of value, *in conjunction with other information*, in building up an intelligent case for Cook). Mr. Gibbons goes on to say that the recent explorations of ice islands "proved without a doubt one fact that cannot be disputed: the first explorer to observe one of these islands was Dr. Frederick Cook . . .". This kind of wild leaping at untenable conclusions does nothing to inspire confidence in the author's methods.

It is to be hoped and expected that the next few years will see a further increase in our knowledge of the Arctic pack ice, and of the Ellesmere Ice Shelf from which the ice islands come. When we have more information on present ice conditions and are better able to estimate conditions pertaining in 1908-9, we shall be in a position to re-evaluate the accounts of Cook and Peary. Until then it seems a waste of time to issue rehashes of old evidence, which can add nothing, and which, if badly presented, can only drive another nail in the coffin of Cook's reputation. Mr. Gibbons might have been well advised to hold his fire until there was something to say, by which time, with luck, he will have matured sufficiently to be able to present it more logically, and to live up to his often repeated claim to analytical objectivity.

A formidable bibliography, listing not only books but also magazine and newspaper articles, shows that the writer has not skimped his research. This list is the most useful part of the well-intentioned but ill-timed monograph.

Moira Dunbar

Mr. T. A. Belcher, Executive Director of the Arctic Institute.

INSTITUTE NEWS

Appointment of Mr. A. T. Belcher as Executive Director

Alan Thomas Belcher, former Deputy Commissioner of the Royal Canadian Mounted Police, has accepted the post of Executive Director of the Arctic Institute of North America. Mr. Belcher will assume his new duties on April 1, 1957 at the headquarters of the Institute in Montreal.

Mr. Belcher has had wide experience in arctic and subarctic affairs in Canada. He was in the service of the Royal Canadian Mounted Police from 1920 to his retirement in 1956, having attained commissioned rank in 1931. Between 1924 and 1932 he served at Herschel Island, Aklavik, Cambridge Bay, and Fort Smith. He has made frequent visits to the Far North since that time. From 1945 to 1946 he was in charge of criminal investigation for the Province of Saskatchewan, and he was in command in the Province of Alberta for six years.

Dr. Walter A. Wood elected President of the American Geographical Society

According to an announcement in the New York *Times* of February 5, 1957 Dr. Walter A. Wood, Treasurer of AINA and Director of its New York office, has been elected President of the American Geographical Society. Dr. Wood has been connected with the Society, which was founded in 1852, since 1929. He participated in more than eighteen of its major expeditions, several times in the capacity of leader. From 1939 to 1942 he was head of the Society's Department of Exploration and Field Research and became a member of its Council in 1954.

Gifts to the library

The Institute library acknowledges with thanks gifts of books and reprints from the following persons and organizations:

Barbara Battle
K. W. Butzer
J. Corbel
M. J. Dunbar
E. Hersmann
A. Löve
Canada, National Research Council
McGill University, University Librarian

Award of Institute research grants

The following have been awarded research grants for field and laboratory investigations by the Institute for 1957 from the Sir Frederick Banting Fund and from funds of the Institute:

Beschel, Roland E. Dept. of Biology and Bacteriology, Mount Allison University, Sackville, N.B., Canada.
Lichen studies on recent glacier moraines in West Greenland to gain glaciological and climatological beyond botanical data.

Ives, John David. McGill Sub-Arctic Research Station, Knob Lake, Quebec, Canada.
Glaciological and geomorphological investigations in Northern Labrador, with particular emphasis on the centres of glaciation and the final centres of deglacierization of the area.

Johnson, Jr., John Peter. McGill University, Montreal, Quebec, Canada.
Continuation of investigations begun in 1956 on emerged strandlines and glacio-fluvial deposits.

Lowther, Gordon R. McCord Museum of McGill University, Montreal, Quebec, Canada.
An archaeological reconnaissance of the Old Crow Flats and their periphery.

Manning, Thomas H. 37 Linden Terrace, Ottawa, Ont., Canada.
Taxonomic studies of some arctic mammals and birds.

MENZER, ELIZABETH. Dept. of Zoology, McGill University, Montreal, Quebec, Canada.

The collection of marine and estuarine benthos, nekton and plankton, collection of endoparasites and ectoparasites of marine and terrestrial vertebrates, preparation of a general report on the collections and notes for publication on one or more of the collections.

OLIVER, DONALD R. Dept. of Zoology, McGill University, Montreal, Quebec, Canada.

Continuation of a research begun in 1956, i.e., taxonomic and life history studies on the chironomids (Chironomidae), and biological, physical, and chemical investigations of a lake near Knob Lake, Quebec.

POWER, GEOFFREY. Dept. of Zoology, McGill University, Montreal, Quebec, Canada.

To make collections from the Koksoak and Whale rivers to substantiate the information on oxygen consumption, growth rate, reproductive potential and migratory habits of Atlantic salmon and brook trout previously obtained and attempt to collect similar information about the arctic char.

RITCHIE, JAMES C. Dept. of Botany, University of Manitoba, Winnipeg, Man., Canada.

To continue and extend floristic and ecological studies of the forest tundra and tundra zones of northern Manitoba. Detail analyses of vegetation and soil and complete collection of vascular plants, bryophytes and lichens.

SJØRS, HUGO. Biological Institute, University of Upsala, Sweden.

Ecological and limnological studies of timberline bogs and lakes in the Hudson Bay lowlands, i.e., the area of Pleistocene marine invasion west of James Bay.

WEEDEN, ROBERT B. Dept. of Zoology, University of British Columbia, Vancouver, B.C., Canada.

To conduct a detailed quantitative study of the environment in which ptarmigan live and the manner in which these birds are adapted to meet problems of survival in the Arctic and to attempt to relate that information to the present distribution of ptarmigan.

Activities in Montreal

On January 31 D. V. Ellis gave an illustrated talk on "Collecting marine animals in the Arctic". During the meeting on March 1 the Geography Department of McGill University discussed the topic "McGill invades the Subarctic". Among the speakers were F. K. Hare, S. Orvig, G. Merril, and C. R. Twidale.

Mr. G. B. Sivertz, Director of Northern Administration, Department of Northern Affairs and National Resources gave an illustrated talk "A summer visit to Greenland" on March 21.

A special meeting was held on March 29 in co-operation with the Franklin Society when Dr. Vilhjalmur Stefansson spoke on the subject "Meat diet and primitive life".

Pictures of products of Eskimo handicrafts from our collection were loaned for a period of two months for exhibition at the Public Library Art Museum, Elsie Perrin Williams Memorial Building, London, Ont.

NORTHERN NEWS

Greenland tourist promotion begun

Greenland is on its way to becoming a centre of tourist attractions; at least the first concrete steps toward developing a tourist industry have been taken. In September of 1956 "Turistforeningen for Grønland" (The Tourist Association for Greenland) was organized at a meeting held in Godthåb, capital of Greenland. The purpose of the organization is to raise funds for construction of tourist facilities in Greenland (hotels, hunting and fishing lodges, boats, etc.) and to publicize the natural scenic appeal, historical interest, and ethnological fascination that the great arctic island has to offer the tourist.

Mr. Lars Lynge, a Greenlander and son of the Danish Member of Parliament for the South Greenland constituency, was named chairman. Mr. Per Bryld, a Dane who was at that time an assistant to Governor Poul H. Lundsteen, became vice-chairman. Mr. Bryld has since returned to the Department for Greenland in Copenhagen but is maintaining his interest in the Association. Other members of the Board of Directors (elected for two years) include the members of the Greenland Provincial Council from Narssak, Godthåb and Egedesminde (all Greenlanders), the co-editor of the newspaper "Grønlandsposten", the "mayor" of Godthåb, and four other gentlemen from various occupations.

The Association solicited members everywhere in Greenland and achieved remarkable success. Within the first eight months over 1,100 out of a total population of 26,000 paid first year's dues of three kroner and received membership cards. Local committees have been formed in all major West Greenland communities and also at Angmagssalik on the east coast where fifty members joined the Association.

Extensive publicity has been given to the organization in the "Grønlandsposten" and over the Greenland radio at Godthåb and there is great enthusiasm among the residents of Greenland, both Danes and Greenlanders.

One important feature that the Association is promoting at the outset is travel within Greenland by residents of the Island. As facilities become available increased publicity campaigns will be undertaken in Denmark and later a concentrated effort will be made to encourage tourists from the United States, Canada, Europe, and the rest of the world. Letters of enquiry have already been received from Denmark, Scotland, Germany, Cuba, and Japan. The Association has recently appointed Mr. Donn K. Haglund of the Geography Department of the University of Pennsylvania, Philadelphia, as its United States representative. The summer of 1957 will see the first group of tourists arrive from Denmark since the Association was formed. The group consists of sportsmen primarily interested in the excellent fishing afforded in the Godthåbfjord.

The Association will soon be legally incorporated under both its Greenlandic name "Kalatdlit-nunane takornariartitsekatigit" and its Danish name "Turistforeningen for Grønland". It has already conducted a very successful fund raising carnival at Godthåb and has acquired its first property for the housing of tourists in the same town. Publication of a news letter and of literature for distribution in Denmark and elsewhere is planned and construction of facilities for the accommodation of large numbers of tourists will proceed as rapidly as funds become available. Encouragement has been given to the Association by the Department for Greenland, the Danish Parliament, and leading Danish and Greenlandic personalities throughout the country.

Donn K. Haglund

A project to use lichens as indicators of climate and time

Crustaceous lichens show remarkable longevity on hard rock. They grow very slowly; for instance, the diameter of the crusts of *Rhizocarpon geographicum* (L.) DC., a cosmopolitan species with a yellowish-green thallus, growing in continental regions of the Alps, increases by less than one inch in 100 years.

The rate of growth reflects the combined effects of various climatic factors and the slowness of growth smooths out the minor fluctuations of the climate. Thus the increase in size of the thallus during a number of years can give a rather accurate mean of the climate for this period. More rapidly growing species, such as the orange-yellow *Caloplaca elegans* (Link.) Th. Fr., common on bird perches, and many foliaceous lichens follow the variations of the annual precipitation in their rate of growth.

The constant rate of growth that prevails in a given region makes it possible to date moraines of the last glacier advances, human monuments, lava flows, and mountain slides. This method that I call lichenometry works well for the last 1,000 years under alpine conditions; in polar regions it should be useful for at least twice that length of time.

To apply lichenometry, however, one must possess reliable data for definite localities. A photograph taken as far back as possible can serve as a basis for establishing such data. For this reason I should like to ask colleagues to set up a pool of lichen photographs from localities where they can be retaken after a number of years, to supply concrete measurements of the growth of the lichens. For this purpose I propose the following procedure.

A collection of lichen photographs should be assembled at the Montreal Office of the Arctic Institute, with my collaboration. Fully annotated prints of pictures would be put at the disposal of any scientist visiting the region at a later date.

A 35 mm. camera with a lens of 50 mm. focal length seems to be the most suitable. Any reasonably fine-grained film will do, but colour film has the advantage of allowing the identification of a greater number of species than black and white film. The pictures should be taken at right angles to the surface of the rock, at a distance of not less than 50 cm. The lower left hand corner of the field should show a lasting identification mark, e.g., a hole chiseled or hammered into the rock. An object of known size, preferably a centimetre scale, should be positioned on the rock near the lower border of the field. The field notes accompanying each picture should give the locality as exactly as possible, e.g., by compass bearings to two landmarks. The erection of a cairn or two would be very helpful, but might consume too much time. The notes should further include the data, the type of camera and lens, the estimated inclination and direction of exposure of the rock face, the type of habitat, and the altitude above sea level.

Any crustaceous and foliaceous lichens will yield important data. Of special interest are lichens that are seasonally submerged in meltwater. Their growth does not depend on the amount of precipitation, but is determined almost exclusively by temperature. Data from these lichens will provide details of some of the complex climatic factors that are integrated by the rate of growth of ordinary rock lichens. Fruticose lichens, such as the so-called reindeer-moss and rock-tripe (*Umbilicaria* spp.) are less suitable.

Anybody having pictures that might be useful for these purposes is cordially invited to send them to the Montreal Office of the Arctic Institute.

ROLAND E. BESCHEL

GEOGRAPHICAL NAMES IN THE CANADIAN NORTH

The Canadian Board on Geographical Names has adopted the following names and name changes for official use in the Northwest Territories and Yukon Territory. For convenience of reference the names are listed according to the maps on which they appear. The latitudes and longitudes given are approximate only.

Wholdaia Lake, 75 SE.
(Adopted April 5, 1956)
Altered applications

Wright Lake	60°42′N	104°43′W
Cochrane Lake	60°53′	104°45′

Chart 5351, Payne Bay and approaches
(Adopted May 3, 1956)

Five Islands	60°11′N	69°24′W	
Ranger Island	60°03′	69°36′	
Ranger Reef	60°02′	69°34′	
Pamiok Island	60°04′	69°34′	
Pamiok Point	60°04′	69°33′	
Guillemot Shoal	60°03′	69°29′	
Ivik Island	59°56′	69°38′	
Alakakvit Summit (hill)	60°04′	69°46′	not Altavik Summit
Kuglukvik Point	60°08′	69°34′	not Kudloovik Point nor Kudluvik Point
Napatak Island	60°02′	69°44′	not Nappatak Island
Agvik Island	60°01′	69°42′	not Arvik Island
Nanuk Islet	60°02′	69°41′	not Nanook Islet
Natsik Islet	60°03′	69°38′	not Natsek Islet
Akunok Islet	60°00′	69°44′	not Akunak Islet
Kidlikpait Islet	59°58′	69°36′	not Kitliat Islet
Kidlikpait Reefs	59°59′	69°35′	not Kitliat Reefs
Tuvak Reefs	59°54′	69°25′	not Tuwak Reefs

Chart 5352, Payne Bay and River
(Adopted May 3, 1956)

Kanik Cove	60°01′N	70°02′W	
Basking Island	59°59′	70°05′	
Lodestone Reef	59°59′	69°58′	
Lodestone Island	59°58′	69°56′	
Sitimat Islands	59°58′	69°50′	
Nakertok Narrows	59°59′	69°55′	
Pikiyulik Island	59°59′	69°54′	not Pikyulik Island
Makok Reefs	59°59′	69°55′	not Malrok Reefs

Chart 5532, Mill Island to Winter Island
(Adopted June 7, 1956)

Bury Cove	65°26′N	87°05′W	
Smyth Harbour	65°11′	83°43′	
Fife Rock	65°12′	82°26′	
Stanley Harbour	64°42′	82°09′	
Sanderson Island	65°35′	83°08′	
Mooneshine Island	65°33′	83°12′	
Sunneshine Island	65°32′	83°02′	
Sokongen Bay	65°45′	83°30′	
Petersen Bay	65°42′	83°52′	
Ivaluardjuk Island	65°45′	84°13′	not Best Island
Donovan Beach	64°45′	82°15′	not South Donovan Beach
Dunne River	64°59′	78°05′	not Scroggs River

Coppermine, 86 NW and 86 NE
(Adopted September 6, 1956)

Lady Nye Lake	67°00'N	117°29'W

Dezadeash, 115A
(Adopted September 6, 1956)
Altered applications

Dezadeash Range	60°40'N	136°55'W
Dalton Range	60°29'	137°10'
Not adopted		
Vokes Peak	60°29'	137°10'

Larsen Creek, 116A
(Adopted September 6, 1956)

Michelle Creek	64°59'N	137°09'W
West Hart River	64°56'	137°04'
Middle Hart River	64°53'	137°00'
Waugh Creek	64°55'	137°02'
Mouse Creek	64°27'	136°56'
East O'Brien Creek	64°05'	137°57'
Altered applications		
O'Brien Creek	64°03'	138°00'
Fish Creek	(Now on map 116B)	

Home Bay, 27 SW and 27 SE
(Adopted October 4, 1956)

Dewar Lakes	68°30'N	71°20'W

Wrigley, 95 0
(Adopted October 4, 1956)

Woodman Head	63°55'N	123°15'W

Foxe Peninsula, 36 SW and 36 SE
(Adopted October 4, 1956)

MacNabb Lake	65°19'N	77°08'W

Mayo Lake, 105 M/15
(Adopted October 4, 1956)

Cobalt Hill	63°59'N	134°57'W

Bathurst Inlet, 76 NW and 76 NE
(Adopted October 4, 1956)

Bathurst Ridge	66°48'N	108°05'W
Breakwater Islands	67°55'	108°30'
Buchan Hills	67°53'	107°45'
Burnside Bay	66°53'	108°00'
Burnside Inlet	66°47'	108°03'
Footprint River	67°51'	107°49'
Hiokitak River	67°08'	107°14'
Tinney Hills	66°50'	107°37'
(Adopted November 2, 1956)		
Wolf Creek	66°34'	107°36'

Northwest Territories and Yukon map
(Adopted December 6, 1956)

Parry Channel	74°20'N	98°00'W

Hazen Strait, 79 SW and 79 SE
(Adopted December 6, 1956)

Skybattle Bay	77°09'N	104°55'W

REPRINTS FROM ARCTIC AVAILABLE AT THE MONTREAL OFFICE

(The figure in bold type, indicating the volume, is followed by the number of the issue, the number of pages, and the price, including postage).

ARMSTRONG, T. Sea ice studies. **7**,3-4 (5pp.) 15c.
AUBERT DE LA RUE, E. Geological survey through the Ungava Peninsula. **1**,2 (1p.) 10c.
BAIRD, P. D. Glaciological research in the Canadian Arctic. **8**,2 (13pp.) 25c.
BAIRD, P. D. and R. P. SHARP. Glaciology. **7**,3-4 (12pp.) 25c.
BAIRD, P. D. *et al.* Baffin Island expedition 1950: a preliminary report. **3**,3 (20pp.) 50c.
———— Baffin Island expedition, 1953: a preliminary field report. **6**,4 (26pp.) 25c.
BANFIELD, A. W. F. Notes on the mammals of the Mackenzie District, N.W.T. **4**,2 (10pp.) 25c.
BEALS, C. S. *et al.* Problems of geophysics in the Canadian Arctic. **7**,3-4 (11pp.) 30c.
BENNINGHOFF, W. S. Interaction of vegetation and soil frost phenomena. **5**,1 (11pp.) 25c.
BERREMAN, G. D. Effects of a technological change in an Aleutian village. **7**,2 (6pp.) 20c.
BERTRAM, G. C. L. Pribilof fur seals. **3**,2 (12pp.) 25c.
———— The Scott Polar Research Institute. **5**,3 (4pp.) 10c.
BLACK, R. F. Eolian deposits of Alaska. **4**,2 (23pp.) 50c.
BÖCHER, T. W. Botanical investigations in southwest Greenland, 1946. **4**,1 (4pp.) 10c.
BÖCHER, T. W. *et al.* Recent biological research in Greenland. **7**,3-4 (12pp.) 10c.
BØGVAD, R. Nepheline syenite and iron ore deposits in Greenland. **3**,2 (9pp.) 25c.
BRANDLY, P. J. and R. RAUSCH. A preliminary note on trichinosis investigations in Alaska. **3**,2 (3pp.) 10c.
BROWN, G. M. Cold acclimatization in Eskimo. **7**,3-4 (11pp.) 25c.
BRUN, E. The Greenlander of today. **2**,1 (11pp.) 25c.
BUGGE, A. The native Greenlander—a blending of old and new. **5**,1 (9pp.) 25c.
BUSS, I. O. The upland plover in southwestern Yukon Territory. **4**,3 (10pp.) 25c.
CHRISTENSEN, N. O. Elections in Greenland. **5**,1 (2pp.) 10c.
CLARKE, C. H. D. Wildlife research in the North American Arctic. **7**,3-4 (11pp.) 25c.
COLBERT, L. O. Geophysical research in Alaska. **7**,3-4 (6pp.) 15c.
———— Tidal data in the North American Arctic. **7**,3-4 (2pp.) 10c.
COLLINS, H. B. Archaeological research in the North American Arctic. **7**,3-4 (11pp.) 20c.
COOK, F. A. Near surface soil temperature measurements at Resolute Bay, Northwest Territories. **8**,4 (13pp.) 30c.
CRARY, A. P. *et al.* Preliminary report on scientific work on "Fletcher's Ice Island", T3. **5**,4 (13pp.) 20c.
DAVIES, F. T. The ionosphere over northern Canada. **7**,3-4 (3pp.) 15c.
DUNBAR, M. J. Arctic and subarctic marine ecology: immediate problems. **6**,2 (16pp.) 25c.
———— *Calanus*, new arctic research vessel. **2**,1 (2pp.) 10c.
———— Langthen og nordpaa (book review). **2**,1 (4pp.) 10c.
———— A note on climatic change in the sea. **7**,1 (4pp.) 10c.
———— The Ungava Bay problem. **5**,1 (13pp.) 25c.
ELLIS, D. V. Some observations on the shore fauna of Baffin Island. **8**,4 (13pp.) 30c.
FRÄNKL, E. J. Crossing north Peary Land. **8**,3 (8pp.) 25c.
FRASER, J. K. Identification of Petitot's Rivière le Roncière-le Noury. **5**,4 (11pp.) 20c.
FREEMAN, T. N. Some problems of insect biology in the Canadian Arctic. **5**,3 (3pp.) 10c.
FREEMAN, T. N. and C. R. TWINN. Present trends and future need of entomological research in northern Canada. **7**,3-4 (9pp.) 15c.
GRAHAM, M. English fishery research in northern waters. **6**,4 (8pp.) 20c.
HAAS, E. DE. A method for measuring the movement of rocks and glaciers with simple equipment. **6**,4 (3pp.) 15c.
HACHEY, H. B. Canadian interest in arctic oceanography. **2**,1 (8pp.) 25c.
HAMMER, M. Some aspects of the distribution of microfauna in the Arctic. **8**,2 (12pp.) 25c.
HARE, F. K. Two pictures of the recent past. **6**,1 (3pp.) 10c.
———— The upper air over northern Canada (book reviews). **3**,1 (2pp.) 10c.
HATTERSLEY-SMITH, G. *et al.* Northern Ellesmere Island, 1953 and 1954. **8**,1 (35pp.) 30c.
HELK, J. V. and M. DUNBAR. Ice islands—evidence from north Greenland. **6**,4 (9pp.) 20c.
HOLTSMARK, B. E. Insulating effect of a snow cover on the growth of young sea ice. **8**,1 (6pp.) 15c.
IRVING, L. The naming of birds by Nunamiut Eskimo. **6**,1 (9pp.) 10c.
ISELIN, C. O'D. Oceanographic problems of the Arctic Ocean. **7**,3-4 (4pp.) 10c.
JOESTING, H. R. Geophysical exploration in Alaska. **7**,3-4 (11pp.) 25c.
KATZ, H. R. Journey across the nunataks of central east Greenland, 1951. **6**,1 (13pp.) 25c.
KIRKPATRICK, C. M. *et al.* Notes on captive sea otters. **8**,1 (14pp.) 20c.
KNUTH, E. An outline of the archaeology of Peary Land. **5**,1 (17pp.) 25c.
KOENIG, L. S. *et al.* Arctic ice islands. **5**,2 (38pp.) 50c.
LAFOND, E. C. Physical oceanography and submarine geology of the seas to the west and north of Alaska. **7**,2 (9pp.) 20c.
LANTIS, M. Problems of human ecology in the North American Arctic. **7**,3-4 (14pp.) 25c.
LAUGHLIN, W. S. and G. H. MARSH. A new view of the history of the Aleutians. **4**,2 (15pp.) 25c.
LEAHEY, A. Soil and agricultural problems in subarctic and arctic Canada. **7**,3-4 (6pp.) 15c.
LEGGET, R. F. Permafrost research. **7**,3-4 (6pp.) 10c.

LITTLEWOOD, C. A. Gravity measurements on the Barnes Icecap, Baffin Island. **5**,2 (7pp.) 25c.
LLOYD, T. Discovery of Russian hydrographic bottles and barges off west Greenland. **5**,2 (1p.) 10c.
——— Meddelelser om Den grønlandske Kirkesag. **5**,3 (2pp.) 10c.
——— North: the nature and drama of the polar world, by Kaare Rohdahl (book review). **6**,4 (2pp.) 10c.
MACCARTHY, G. R. Recent changes in the shoreline near Point Barrow, Alaska. **6**,1 (8pp.) 20c.
MADILL, R. G. The search for the north magnetic pole. **1**,1 (11pp.) 25c.
MALAURIE, J. The French geographical expedition to Thule, 1950–1951: a preliminary report. **8**,4 (13pp.) 30c.
MANNING, T. H. Narrative of an unsuccessful attempt to circumnavigate Banks Island by canoe in 1952. **6**,3 (28pp.) 40c.
——— Narrative of a second Defence Research Board expedition to Banks Island, with notes on the country and its history. **9**,1-2 (77pp.) 60c.
——— Notes on the fish of Banks Island. **6**,4 (2pp.) 10c.
——— Remarks on the reproduction, sex ratio, and life expectancy of the varying lemming, *Dicrostonyx groenlandicus*, in nature and captivity. **7**,1 (13pp.) 25c.
——— Remarks on the tides and driftwood strandlines along the east coast of James Bay. **4**,2 (9pp.) 25c.
MANNING, T. H. and R. W. RAE. Tidal observations in arctic waters. **3**,2 (10pp.) 25c.
MANSFIELD, A. W. Eastern arctic fisheries investigations, 1947–55. **8**,2 (3pp.) 35c.
MARIER, G. Recent studies on vitamins (book review). **4**,1 (3pp.) 10c.
MARSHALL, E. W. Structural and stratigraphic studies of the northern Ellesmere ice shelf. **8**,2 (6pp.) 20c.
MEIER, M. F. *et al.* Preliminary data from Saskatchewan Glacier, Alberta, Canada. **7**,1 (24pp.) 35c.
METCALF, W. G. A note on arctic oceanography and the Lomonosov Range. **7**,2 (2pp.) 10c.
MICK, A. H. and H. A. JOHNSON. Soil resources and agricultural development in Alaska. **7**,3-4 (13pp.) 25c.
MILLER, R. S. A survey of the mammals of Bylot Island, N.W.T. **8**,3 (11pp.) 25c.
MONTGOMERY, M. R. Further notes on ice islands in the Canadian Arctic. **5**,3 (5pp.) 10c.
MORRISON, P. R. and W. J. TEITZ. Observations on food consumption and preference in four Alaskan mammals. **6**,1 (6pp.) 10c.
MUNTZ, A. P. Recent glacier activity in the Taku Inlet area, southeastern Alaska. **8**,2 (13pp.) 25c.
New vessels for ice navigation in Canada. **1**,2 (3pp.) 10c.
NIELSEN, F. Planned reforms in Greenland. **4**,1 (6pp.) 10c.
NUTT, D. C. The *Blue Dolphin* Labrador expeditions, 1949 and 1950. **4**,1 (10pp.) 25c.
——— Second (1948) U.S. Navy antarctic development project. **1**,2 (5pp.) 10c.
PAULS, F. P. Enteric diseases in Alaska. **6**,3 (8pp.) 20c.
PETERSEN, H. The Danish meteorological service in Greenland. **1**,1 (7pp.) 25c.
POLUNIN, N. *et al.* Aerobiological investigations in the Arctic and Subarctic. **1**,1 (2pp.) 10c.
PORSILD, A. E. A biological exploration of Banks and Victoria islands. **3**,1 (10pp.) 25c.
——— Edible plants of the Arctic. **6**,1 (20pp.) 25c.
RAE, R. W. Joint arctic weather project. **4**,1 (9pp.) 25c.
——— Meteorological activities in the Canadian Arctic. **7**,3-4 (10pp.) 25c.
RAND, A. L. The ice age and mammal speciation. **7**,1 (5pp.) 15c.
RAUP, H. M. Some botanical problems of the arctic and subarctic regions. **6**,2 (7pp.) 10c.
RAUSCH, R. Notes on the Nunamiut Eskimo and mammals of the Anaktuvuk Pass region, Brooks Range, Alaska. **4**,3 (50pp.) 50c.
——— Observations on a cyclic decline of lemmings (*Lemmus*) on the arctic coast of Alaska during the spring of 1949. **3**,3 (12pp.) 25c.
——— On the status of some arctic mammals. **6**,3 (58pp.) 50c.
RAWSON, D. S. Limnology in the North American Arctic and Subarctic. **6**,3 (7pp.) 15c.
RAY, L. L. Permafrost. **4**,3 (8pp.) 25c.
REED, J. C. and H. S. BOSTOCK. Research in geology and geomorphology in the North American Arctic and Subarctic. **7**,3-4 (12pp.) 20c.
REICHELDERFER, F. W. Meteorological services in Alaska. **1**,1 (8pp.) 25c.
[Field] research projects sponsored by the Arctic Institute of North America. **7**,3-4 (13pp.) 15c.
REX, R. W. Microrelief produced by sea ice grounding in the Chukchi Sea near Barrow, Alaska. **8**,3 (10pp.) 20c.
ROBINSON, E. Some instances of unstable surface temperature conditions during an arctic winter. **8**,3 (10pp.) 20c.
RODAHL, K. "Spekk-finger" or sealer's finger. **5**,4 (6pp.) 10c.
ROSS, J. E. R. Geodetic investigations in the Canadian Arctic. **7**,3-4 (4pp.) 10c.
ROUSSEAU, J. By canoe across the Ungava Peninsula via the Kogaluk and Payne rivers. **1**,2 (2pp.) 10c.
ROWLEY, G. W. Settlement and transportation in the Canadian North. **7**,3-4 (7pp.) 20c.
——— An unusual archaeological specimen from Foxe Basin. **3**,1 (3pp.) 10c.

lf.

p.)

0c.
3-4

four

pp.)

10c.

0c.
region,

oast of

c.
North

p.) 15c.
Barrow,

arctic

ers. 1,2

20c.

C

G

Ic

D

In

N

G